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ON THE HEAT RADIATION OF *ARCTURUS*, *VEGA*, *JUPITER*, AND *SATURN*.

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IN 1888 Professor C. V. Boys,[1] equipped with his newly invented radiomicrometer, began a series of measurements to determine the heat radiation of the brighter stars. The published results of the work of Dr. Huggins,[2] in 1869, and of Stone's experiments[3] on the same subject, in 1870, had encouraged him to hope that the far greater sensitiveness to heat radiation, gained in the new radiomicrometer over the thermopile (or thermojunction) and galvanometer used by Huggins and Stone, might make possible a comparison of even the fainter red stars, comets and nebulæ. The failure which attended the earlier observations on the brightest stars and planets led to an effort toward greater delicacy in the apparatus, and a higher degree of sensitiveness in the radiomicrometer was reached.

In Boys' apparatus the receiving surface of a radiomicrometer suspension was mounted in the focus of a 16-inch reflecting

[1] C. V. BOYS, *Proc. Roy. Soc.*, **47**, 480, No. 291, 1890.

[2] W. HUGGINS, *Proc. Roy. Soc.*, **17**, 309, 1868–9.

[3] E. J. STONE, *Proc. Roy. Soc.*, **18**, 159, 1869–70.

telescope of 67.8 inches focal length. The most delicate suspension employed presented a blackened receiving surface of 4 sq. mm at the sensitive junction, and was hung from a quartz fiber of $\frac{1}{5750}$ inch diameter. The period of vibration was 10 seconds and the sensitiveness was such that without mirrors or lenses for concentration, the heat from a candle at a distance of 60 inches gave a deflection of 60 mm. A further test of the sensitiveness of the radiomicrometer connected with the reflector showed that on a dry, clear night a deflection of 38 mm could be obtained from a single candle at a distance of 250.7 yards.

Professor Boys' observations were continued, at intervals, from September 1888 to April 1890, and the objects observed were the Moon, *Venus*, *Jupiter*, *Saturn*, *Arcturus*, *Vega*, *Capella*, *Altair*, and other stars. With the sensitiveness used, $\frac{1}{150000}$ of the heat sent by the full Moon to the mirror could have been detected. Slight deflections, which Boys himself regarded as of questionable origin, were obtained on one occasion from *Venus*. From none of the other planets nor stars were any indications of heat observed; certainly not as much, according to Boys' reckoning, as would be received by the mirror from a candle at the distance of 1.71 miles, were it not for atmospheric absorption. Boys' results show conclusively that the heat effects obtained by Huggins and by Stone must have been from accidental sources and could not have been due to the radiations from the stars, to which they were attributed. The measurements to be given later in the present paper will be seen to justify Boys' conclusions concerning his own measurements, and to confirm (were further confirmation necessary) his opinion of the accidental origin of the heat measured by Huggins and Stone.

Mr. T. A. Edison,[1] while with the Draper eclipse party at Rawlins, Wyoming, in 1878, made a short series of observations on *Arcturus* to test the sensitiveness of his micro-tasimeter. The tasimeter was placed in the principal focus of a 4-inch Dolland telescope. The result of five successive exposures gave consistent deflections on the side of heat. No very trustworthy

[1] T. A. EDISON, *Am. Jour. Sci.*, **67**, 52, 1879.

statements of the sensitiveness of the micro-tasimeter were accessible to the writer. One statement[1] gives the sensitiveness as such that the "heat of the hand at a distance of six or eight inches threw the galvanometer light-spot off the scale," a feat not beyond the powers of a moderately good thermopile in connection with a sensitive galvanometer. Again,[2] it is stated that the instrument, in Mr. Edison's hands, was capable of "measuring the one fifty-thousandth of a degree of heat."

The radiometer used in the present study is shown later to have been at least twelve times more sensitive than Boys'[3] radiomicrometer, which would show the one one-millionth of a degree rise of temperature.

It appears, therefore, that an instrument capable of measuring temperature differences of the order of one ten-millionth of a degree Centigrade, placed in the principal focus of a mirror of two feet aperture, is required to show any indication whatever of heat from *Arcturus*. For a 4-inch aperture, a sensitiveness corresponding to the one one-hundred-millionth of a degree, or, more probably, the one one-thousand-millionth of a degree, would be necessary. That measurements with such a sensitiveness would be practically impossible with any except a compensating instrument, my own experience makes certain. That it is very easy to mistake deflections from accidental sources for legitimate ones, the experiments of Sir W. Huggins and Dr. Stone, just cited, are ample evidence. It appears likely, therefore, that Mr. Edison was deceived in his supposed indications of heat from *Arcturus*.

Later, Minchin,[4] working with a selenium photo-electric cell in the focus of a two-foot reflector, measured electromotive forces due to radiations from several planets and stars. It will appear later, in a comparison between Minchin's values and corresponding values given in the present paper, that the photoelectric cell seems to be strongly selective in its action outside the visible spectrum; so that its indications are probably not in

[1] *Chem. News*, **38**, 57. [2] *Chem. News*, **38**, 26. [3] C. V. Boys, *loc. cit.*, p. 496.

[4] G. M. Minchin, *Proc. Roy. Soc.*, **58**, 142, 1895.

proportion to the total radiant energy received from the star: a conclusion which Boys' results serve equally well to establish.

THE APPARATUS.

1. *The radiometer construction.*—The heat measuring instrument used in the present study was of the same type as the compensating torsion radiometer, of which a description has already appeared.[1] The case of the instrument was made from a block of bronze $5 \times 5 \times 10$ cm, the long axis of which was bored out from the top to within 7 mm of the bottom, by a hole 3 cm in diameter (Fig. 1). Communicating with this axial boring were three lateral borings. Into a boring in the middle of the front face was soldered a tube 22 mm in diameter and 22 mm long, capped at the inner end by a circular brass plate with a central circular opening 13 mm in diameter. A screw thread cut inside this tube near the inner end was fitted by a ring nut. This window was closed by a fluorite disk 21 mm in diameter and 3.41 mm thick, with plane parallel faces. The air-tight packing used during the summer of 1898 consisted of rubber washers smeared with Ramsey's preparation of paraffin, india-rubber and vaseline. These were placed before and behind the fluorite window. Pressure against the packing was produced by screwing up the ring nut. In the work two years later the window was simply cemented into place by Chatterton wax. The apex of the cone of star rays from the condensing mirror entered the radiometer by traversing the fluorite window, and could be directed to fall on one of the blackened surfaces of the suspension directly behind the window. On the opposite side of the bronze case a circular boring 11 mm in diameter was made, coaxial with the boring for the front window just described. The hole was earlier covered by a plate of glass cemented on the back of the case, but later by a plate of fluorite to fit the instrument for the purpose of another study. Through this window at the back of the case, the star image in the radiometer, and the blackened vanes of the suspension, could be seen at the same time. The

[1] E. F. NICHOLS, *Physical Review*, **4**, 297; also *Wied. Ann.*, **60**, 401, 1897.

third boring, 17 mm in diameter, entered the bronze well 25 mm lower than the other two, and on the left hand face of the block, as seen from the front. A piece of good plate glass was cemented over this opening, through which the deflections of the suspension were read by the telescope and scale method. To the top surface of the bronze case, a circular glass plate 73 mm in diameter, with a central circular opening 35 mm in diameter, was cemented. Upon the upper surface of this plate rested a small bell of glass terminating in a tube. The flange of the bell was well ground upon the upper surface of the circular plate. In the tube a short distance above the bell, was a stopcock with oblique bore. Beyond the stopcock the tube was attached by a rubber connection to a glass tube leading from a drying bottle, which contained phosphoric anhydride. Another glass tube leading away from the drying bottle was connected by a short rubber connector to a Geissler mercury air pump. The rubber connections were all smeared on the outside with the Ramsey preparation, which made them nearly enough air-tight for the purpose in hand. In the interior of the bronze case near the top, a narrow brass ring was soldered, and upon this ring rested a light bridge, *c* (Figs. 1 and 2). A torsion head, *a*, carrying the upper end of the suspension, was in turn carried in a small square brass block *b*, free to slide in a slot in the bridge *c*, permitting the suspension to be brought closer to, or withdrawn from, the fluorite window in front of it. The radiometer case was mounted on a tripod with leveling screws (not shown in the cuts).

The radiometer suspension was built up on a whip of fine drawn glass 32 mm long, to the lower end of which was attached a small plane mirror 2.2 by 3 mm, made by silvering a fragment of very thin microscope cover glass. On the axis 22 mm above the mirror, and in a plane at right angles to it, a delicate cross arm of drawn glass was fastened, bearing on its extremities the two blackened radiometer vanes *dd*. The sensitive vanes were circles approximately 2 mm in diameter, which, to secure lightness and uniformity, were stamped out of thin mica

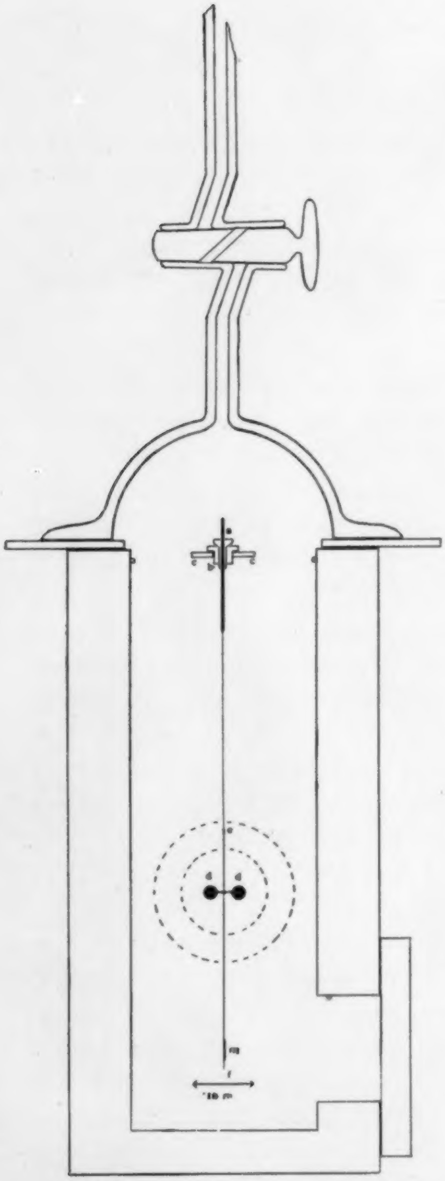


FIG. 1.

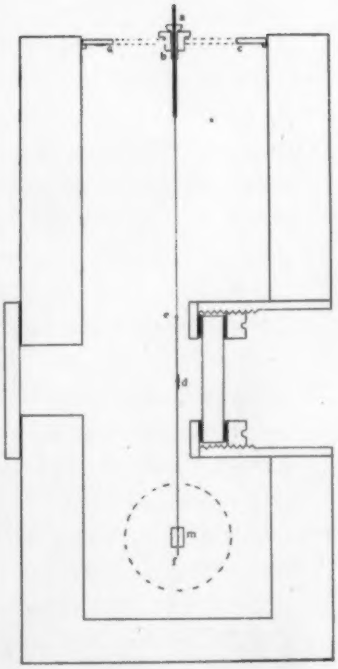


FIG. 2.

with a circular steel punch, made for the purpose. These vanes were uniformly coated with lampblack, and mounted as symmetrically as possible with reference to the axis of rotation *ef*. To the upper end of *ef* a very fine quartz fiber 32 mm long was attached. The upper end of the fiber was made fast to a bit of steel wire, which passed up through a small hole in the axis of the torsion head *a*. The distance between the centers of the vanes was 4.5 mm. The attachments of the fiber, and of the small glass rods and mica disks were all made with shellac. No delicate balance was available, so the exact weight of the suspension could not be ascertained, but from comparison with several similar suspensions built earlier, its weight ought not to have exceeded 6 or 7 mg.

2. *The radiometer as a measuring instrument.*—It is hardly probable that the form and dimensions of the radiometer here described could have been of the most favorable proportions for the greatest sensitiveness. The whole matter of the radiometric activity is too little understood to make theoretical speculations on the best form or proportions of parts of much practical value. My own experience, furthermore, has been too short to lead to any exact quantitative rules for construction. The instrument, as described, was built with the following considerations in mind: (1) It appeared from earlier experience that the maximum sensitiveness of the radiometer, as it changes with the pressure of the enclosed gas, increases as the vanes are brought nearer the window in front. They cannot be brought too near the window, however, and still keep the deflections closely proportional to the energy received for deflections widely different in magnitude. In the present instrument the vanes were from 2.5 to 3 mm behind the fluorite window. For this distance it has been proved in an earlier paper[1] that the deflections are proportional to the energy causing them. (2) The instrument must have as short a period as is consistent with a high sensitiveness. In the radiometer used in 1898, the period was 11 seconds, so that the maximum effect of an

[1] E. F. NICHOLS, *loc. cit.*, p. 300.

exposure to a source of radiation was reached in $5\frac{1}{2}$ seconds. To accomplish this, as well as to insure a more constant zero by giving nearly equal exposure of both vanes to all objects in front of the radiometer, the vanes were brought close together. (3) The sensitiveness seems very closely related to the damping, and this in an inverse order. For that reason the vanes were made as small as possible, and still be large enough to receive the whole planet or star image. In this way, with vanes of π sq. mm exposed surface, a sensitiveness per sq. mm was obtained, six times as great as that (with nearly the same period) in a suspension with rectangular vanes 2×16 mm. It would doubtless have been better to still further reduce the size of vanes, if the work could have been done with sufficiently well figured reflectors so that perfect images had been possible. (4) Sensitiveness of the vanes under all circumstances is most intimately connected with the pressure of the surrounding gas. The pressure corresponding to maximum sensitiveness could not be measured, because no pressure gauge was at hand. In a similar instrument, but with larger vanes, a pressure of 0.05 mm of mercury gave maximum sensitiveness. Fortunately the curve of sensitiveness, as dependent upon pressure, is a curve somewhat flattened at its maximum. Small changes of pressure at this point affect the sensitiveness but little. Some standard of radiation, such as a Leslie cube, or in very crude work, a candle, is needed as a reference, because there is no way of referring the sensitiveness in the radiometer, as in the bolometer, to anything as definite as the period of a galvanometer and the current through a bridge. It ought to be possible, however, by improved construction, to make the radiometer case more completely air-tight, or else to calibrate the sensitiveness as a function of the pressure, and measure this. I have not so far used the radiometer in a way which made such precautions necessary.

As compared with the bolometer or thermopile, the present form of radiometer has the following advantages: (1) It is uninfluenced by all magnetic and thermoelectric disturbances, which beset a sensitive galvanometer. (2) The radiometer is

free from any disturbances corresponding to the convection currents which arise about a heated bolometer strip. It has, however, the following disadvantages: (1) It is not so easily portable as the thermopile or bolometer. (2) All rays to be measured must traverse the window of the radiometer and be subject to its selective absorption and reflection.

3. *The arrangement of reflectors.*—Observations were made in the month of August in the summers of 1898 and 1900. The arrangement of mirrors in the two series differed sufficiently to make separate description of the schemes desirable. The two plans are shown in Figs. 3 and 4.

The room in which the experiments were made was the heliostat room[1] of the Yerkes Observatory. This room could hardly be improved in its appointments for the work in hand, and was in fact designed purposely for work of a similar nature. The gallery to the left of the double partition is provided with a movable roof and sides, which slide back between the walls of the enclosed room to the right, leaving only a low parapet above the level of the floor. The only openings through the double partition are a window large enough to admit the beam from the heliostat at *H*, and a passage way closed by double doors. The beam from the heliostat fell upon a two-foot (61 cm) concave mirror *M* of 7 ft. 9 in. (233 cm) focal length, figured and silvered by Mr. G. W. Ritchey. The converging cone was caught on a small 45° flat mirror, *f*, 4 × 6 inches (10.2 × 15.4 cm), and directed thence into the radiometer case through the fluorite window, the focal point lying in the plane of the vanes. The heliostat, *H*, used in 1898, was of a modified Foucault type, built by Adam Hilger, and belonging to the Allegheny Observatory. It was made to carry a 17-inch flat mirror, and was earlier used by Professor S. P. Langley in his work on the temperature of the Moon. As it was necessary to get a larger beam to fill the aperture of the 2-foot concave mirror, Mr. Ritchey selected from many pieces a sheet 30 × 36 inches (76.2 × 91.4 cm) of best commercial plate glass ⅜ in.

[1] GEORGE E. HALE, ASTROPHYSICAL JOURNAL, 5, 260, 1897.

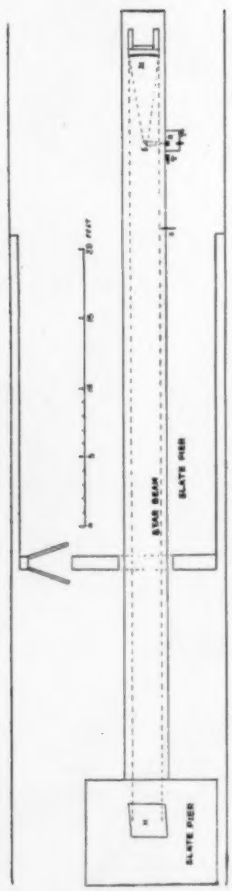

STAR BEAM
SLATE PIER
SLATE PIER
FIG 3 1898

FIG. 3.

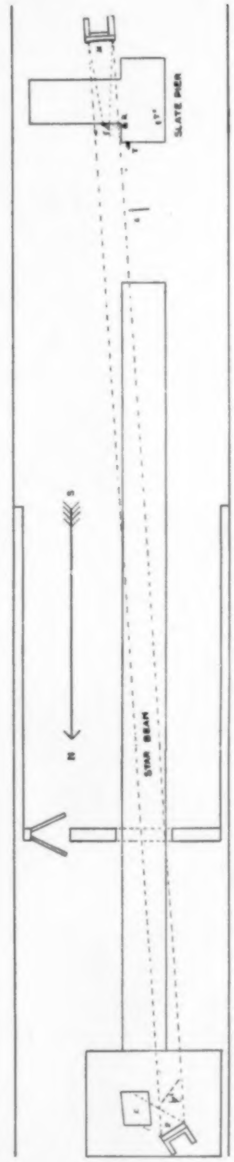

SLATE PIER
S
N
STAR BEAM
FIG 4 1900

FIG. 4.

thick. This plate was silvered by Mr. Ritchey, and mounted in a frame attached to the metal cell of the heliostat. Its thickness was not great enough to support its weight, and preserve a plane surface. Mr. Ritchey accordingly introduced a system of three levers in the bed of the frame, each lever pivoted at the middle, and carrying a cushion on either end. The glass rested on the cushions in such a way that each cushion was at the geometrical center of each sixth part of the mirror. By this means images sufficiently good for the purpose were in most cases obtained. The heliostat had unfortunately been a good deal worn and racked by use, and the load of the large mirror was more than it was built to carry, so that the manner of its driving and adjustment left much to be desired. The radiometer, *R*, was mounted on a wooden table, standing on an overhang built out from the long slate pier shown in the diagram. An observer at the telescope, *T*, read the deflections of the radiometer in millimeter divisions on a scale at *S*, behind and above him at a distance of about 6 feet (183 cm) from the radiometer. Cords connected to the slow motions on the heliostat were brought to a point within convenient reach of a second observer at the telescope *T′*, which was focused on the sensitive vanes, as seen through the window in the back of the radiometer case. The latter observer could keep the star image constantly in sight, except when it fell upon one of the vanes, in which case a very small quantity of stray light in the image showed its position.

THE AUGUST 1898 OBSERVATIONS.

The first series of observations was made on *Vega*, the night of August 3, 1898. From July 5, when the work was begun, the time had been spent in building the radiometer and in assembling and adjusting the auxiliary apparatus. The work on the radiometer suspension was too hastily done, with the result that although the sensitiveness was in the main sufficient, the compensation was so poor that small disturbances in the sky and temperature changes in the room had too great an effect on

the zero. A light cardboard house was built around the radiometer case, which partly shielded it against sudden draughts, but its restlessness was in greater part due to unsteady sky conditions. It was found later that the coat of lampblack on the inside wall of the case, directly opposite the fluorite window, had been marred in a way to expose a portion of the cylindrical surface of the metal. Rays which came from the mirror in a particular direction and were focused in the plane of the vanes, were reflected by the exposed wall and brought to a focus on the back surface of one vane. This discovery accounted for some of the restlessness of the suspension in use.

The method of observing.— As a result of the experience of others, it was obvious at the outset that no form of shutter could be used in making the observations, and that to obtain results of any value the radiation from the star must be directly compared with that from the open sky, at a point very near the star. It was further desirable that the motion of the mirror, by which the star image was exchanged for a sky image, should be small, and take place as far from the radiometer as possible. With an observer at each of the telescopes T and T', the observer at T watched the motion of the radiometer, and waited for a period of comparative quiet which would bring the image of the scale to rest; then signaled to the observer at T' to throw the star image on the vane, or off it, as the case might be, by means of the cords running to the slow motion of the heliostat. Had the heliostat always obeyed the cords with a consistent action, the difficulties of observation would have been greatly simplified. Any delay in bringing the star image on, or off, the vane at the signal of the first observer, was disastrous, for the radiometer rarely maintained the almost absolute quiet necessary for a successful measurement of such minute deflections, longer than the five or six seconds required for the legitimate deflection to take place. Under the most favorable circumstances, very few uninterrupted deflections were obtained, and many contradictory single deflections were the rule in every series. These harassing disturbances were often considerably

greater than the deflection caused by the star; so that the only hope lay in the fact that they were strictly accidental and not systematic, and that therefore they would neutralize in making up the average of a long series of deflections. This has proved to be the case. At a given signal from the observer at *T*, the image of the star was thrown on one of the vanes, if off, or *vice versa*, and after a suitable time the radiometer deflection was read. In this way the throw in one direction only was taken. If the external conditions could have been depended upon to remain stationary, it would have been advantageous to read the return swing by undoing the previous change at the first reading. This, however, was out of the question. So that if the star image was thrown on one of the vanes, it was in general, though not invariably, kept there after the deflection was taken, to await another season of comparative quiet. In collecting and comparing the deflections at the close of a series, they were divided into two sets, called "on" observations, when the star image was thrown on one of the vanes, and "off" observations, corresponding to the deflection obtained when the image was moved off the vane. Thus the average of the "on" observations should show a repulsion between the fluorite window and the vane on which the star image was thrown, and the "off" observations should show an apparent attraction between the vane and the window. The direction of the apparent movement of the scale thus produced would depend on which vane was used; one vane giving, for the same treatment, a deflection opposite in direction to that of the other.

In averaging a series of observations to determine the quantity of heat received, the "on" observations and the "off" observations were averaged separately. The average of the "on" observations in all series, save the series of August 4 on *Vega*, showed repulsion between the vane on which the star image fell and the window in front. The averages of the "off" observations in the fourteen series made, without exception, showed attraction between the vane and window.

In computing the probable error, given in the combined

average column in the tables, the residuals of the individual "on" observations were made up with reference to the average of the "on" observations in each series, and the residuals of the individual "off" observations, with reference to the average of the "off" observations. The probable error was then computed from the sum of the squares of both sets of residuals and the combined number of "on" and "off" observations, in the usual way. The reason for this method of treatment lies in the consideration that during many of the series there was a very small but persistent drift of the zero in one or the other direction, the effect of which would be to augment either the "on" or the "off" observations, at the expense of the other. The fact that only one set of the "on" or "off" observations, in a total of 28, gave a contradictory result, shows the average drift in all but this one case to be less than the counter influence of the star.

It was extremely important, in measuring such small deflections under disturbed conditions, that the observer at *T* should be wholly unprejudiced. This was accomplished by Mr. Colton, who sat behind the radiometer, arranging in his own mind a series of signals, which were used to call a change by the observer at *T*, who was kept in ignorance as to which signal meant "off" and which "on;" further, he did not know which vane of the radiometer was in use. On his part he kept the deflections read to himself, so that the observer at *T'* did not know what results the radiometer was showing in response to his management of the star image. At the end of a series, the record of deflections was compared with the signals and its indication of heat or cold for the star image was determined. To prevent the large deflections which were sometimes obtained (in which the star could obviously have had but little part) from exerting an overwhelming influence upon the average, it was decided to throw out all deflections greater than 2 mm, irrespective of their direction, as well as deflections which were spoiled by an evidence of some extraneous disturbance, setting in before the signal could be executed.

Sensitiveness of the apparatus.—It was found impracticable, without spending too much time, to make the radiometer case perfectly air-tight. It was consequently necessary, once in two or three days, to pump it out in order to maintain the requisite sensitiveness, which ran down slowly from the maximum point, as the pressure increased through leakage. As has been already mentioned, it was advisable to keep track of the sensitiveness from time to time, by measuring the throw obtained from some reasonably constant source. As the work on the stars was so very roughly quantitative, due to changing atmospheric absorption, as well as to the difficulty in accurately measuring such minute deflections under the uncontrollable conditions which surrounded the work, it was decided that with reasonable care and attention to the flame, a candle at a distance from the instrument would most conveniently serve the purpose. It should be borne in mind, that the *total radiation* from a candle is subject to smaller variations than the *photometric intensity*. No standard candles were to be had, but a uniform grade of paraffin candles was obtained, which normally burned 7.6 grams of paraffin per hour.

Such a candle was placed at a distance of 830 cm (27 ft. 3 in.) from the radiometer. A small silvered flat mirror was interposed in the path to direct the candle rays into the radiometer. In determining the sensitiveness, the candle was lighted and left to burn until its flame had assumed approximately normal height and diameter, and then five or six exposures were made by raising a shutter near the candle. Deflections were taken in the one direction only, *i. e.*, not counting the return swing. The average was taken as the sensitiveness. The changes in sensitiveness with time were so gradual that one determination was sufficient for an evening's work.

The sensitiveness of the radiometer during each series of observations, in terms of a candle 830 cm distant, is given in the "sensitiveness" column in the tables. The sensitiveness for direct comparison with the star heat can perhaps be best gotten at roughly, by computing the deflection which should be caused by all the heat from a candle one meter distant, which fell on a

surface equal to the effective aperture of the 2-foot mirror. From the law of inverse squares, a deflection of 7.5 mm from a candle 830 cm distant (the mean of the sensitiveness actually used) would correspond to a deflection of 520 mm for a candle one meter distant. The ratio of the surface of the radiometer vane to the effective aperture of the concave mirror was approximately 1 : 94968. The corresponding deflection for all the heat from a candle one meter distant, incident upon the aperture of the concave mirror, should be $520 \times 94968 = 49380000$. A deflection of 1 mm, for a star at this sensitiveness, would thus signify that the intensity of the star's radiation was about one forty-nine-millionth part of that of a candle at a distance of one meter. The mean of the results for *Arcturus*, in the combined average column reduced (without correction for atmospheric absorption) to sensitiveness 7.5, was 0.53 mm; the heat from *Arcturus* would thus be something greater than the one one-hundred-millionth part of the heat from a candle at a distance of one meter.

The column headed "Sens. 10^{-8} meter-candle," in Tables I and II, contains the "Combined average," reduced to sensitiveness 15.4 mm, for comparison. For this sensitiveness, 1 mm would correspond to the one one-hundred-millionth part of the heat from a candle 1 meter distant, incident upon a disk equal to the effective aperture of the concave mirror. The last column in the table shows the average zenith distance of the star during each series of observations. The column headed "No. neg. obs.," gives the total number of deflections of wrong sign obtained in each series.

Description of the nights on which observations were made.— August 3. Sky cleared after several days of stormy weather; fairly transparent; full Moon.

August 4. Sky thick and whitish; thermal conditions very unsteady.

August 5. Sky somewhat more transparent than on previous night and thermal conditions steadier; sky clouded over by 10 P.M.

August 7. Sky, between clouds, very transparent; break of

one half hour in series on *Arcturus* because of clouds; completely clouded over at 9:45.

August 8. Sky clear and fairly transparent; gentle east wind.

August 9. Sky thick and white; fresh east wind; thermal conditions unsteady.

August 11. Sky clear, but only moderately transparent.

August 13. Sky thick; conditions during series on *Arcturus* much disturbed; lightning in the west; western sky whitish.

TABLE I.

ARCTURUS. AUGUST 1898.

Date	Time P.M.	"On" obs.		"Off" obs.		No. neg. obs.	Combined average	Sens.	Sens. 10^{-8} meter candle	Zenith dist.
		No.	Av.	No.	Av.					
4	8.00–9.30	18	0.32 mm	20	0.48 mm	11	0.40 mm ± 0.08	8.4	0.65	49° 40′
5	8.00–9.05	24	0.42	21	0.50	11	0.45 ± 0.11	6.6	1.06	47° 20′
7	8.40–9.45	14	0.94	12	0.61	5	0.78 ± 0.11	7.5	1.60	56° 10′
8	7.45–9.45	7	0.67	13	0.61	5	0.63 ± 0.11	7.5	1.30	55° 10′
9	8.30–9.45	15	0.50	32	0.43	12	0.45 ± 0.11	7.1	0.98	56° 50′
11	8.30–9.15	14	0.57	14	0.25	9	0.41 ± 0.13	4.6	1.36	60° 30′
13	7.45–9.45	14	0.40	8	0.30	9	0.36 ± 0.17	8.2	0.68	55°
									Mean	54° 45′

TABLE II.

VEGA. AUGUST 1898.

Date	Time P.M.	"On" obs.		"Off" obs.		No. neg. obs.	Combined average	Sens.	Sens. 10^{-8} meter candle	Zenith dist.
		No.	Av.	No.	Av.					
3	9.45–11.00	36	0.45 mm	38	0.28 mm	19	0.36 mm ± 0.06	10.0	0.55	8°
4	10.30–12.00	15	−0.14	17	0.46	9	0.17 ± 0.07	8.4	0.31	18° 40′
8	10.00–11.30	21	0.16	24	0.44	14	0.31 ± 0.08	7.5	0.64	19° 50′
9	9.45–11.00	17	0.12	23	0.17	16	0.15 ± 0.11	7.1	0.33	12° 40′
11	10.15–10.50	10	0.11	10	0.24	9	0.18 ± 0.12	4.6	0.60	15° 40′
12	10.00–10.30	10	0.09	11	0.36	5	0.21 ± 0.08	6.5	0.50	13° 20′
13	9.45–11.00	23	0.37	24	0.36	15	0.36 ± 0.09	8.2	0.68	14° 30′
									Mean	14° 45′

On the night of August 12 the method of observing was tested in two ways, to discover whether any heat effects could be detected, due to the movement of the heliostat mirror in throwing

the star image on and off the vane. A series of sixteen observations (sensitiveness 6.5), was made on a star too small to affect the radiometer, and used only as a mark in the sky. The measurements were carried out, and the results treated, in precisely the same way as in the series on *Arcturus* and *Vega*. The resulting "combined average" for the star was 0.03 mm, indicating cold. Immediately following, another series of sixteen observations was made with the same star in the field, but only moved back and forth underneath the vane, not touching it. The combined average was likewise 0.03 mm, indicating heat when the star image was directly under the vane. The smallness of these values is purely accidental, as the probable errors in the regular series run much higher. The tests serve merely to show that no considerable systematic error was introduced in the working of the apparatus.

Table III shows a comparison between the different series on *Arcturus* and on *Vega*, for the five nights on which both were observed. It must be borne in mind, however, that the candle heat in terms of which the sensitiveness was measured suffered but one reflection on silver, while the star heat was reflected from three surfaces before entering the radiometer; further, that the heat in all cases lying beyond 8 μ was *largely*, and that beyond 9.4 μ *entirely*, absorbed by the fluorite window. No correction is here introduced for atmospheric absorption, which was greater in the case of *Arcturus* than of *Vega*, as the zenith distances in Tables I and II show.

TABLE III.

ARCTURUS AND *VEGA* COMPARED.

Date	*Vega*	*Arcturus*	$\frac{Arcturus}{Vega}$
Aug. 4	0.31 mm	0.65 mm	2.1
8	0.64	1.30	2.0
9	0.33	0.98	3.0
11	0.60	1.36	2.3
13	0.68	0.68	1.0
Means	0.51 mm	0.99 mm	2.1

In Tables I and II the range between the highest and lowest values for *Arcturus* and *Vega* is seen to be as 2 to 1. Different conditions of the sky on different nights, and at different times during the same night, doubtless account for much of this; also the difficulty of accurate measurement of such minute deflections under disturbed conditions. Lastly, the astigmatism of the heliostat mirror was not always the same. The consequent form of the star image changed in such a way that it was often impossible to center it on the vane, and frequently it was slightly larger than the vane. In Table III the ratios are as accordant as it is reasonable to expect. In the observations of August 13 *Arcturus* was so low in the west that a thunder-storm, which was gathering in that quarter, would explain the low value obtained if a host of other accidental reasons might not have caused it. The observers in the measurements so far given were invariably Mr. Colton and the writer.

The 1898 series was here necessarily brought to a close by the pressure of other engagements.

THE AUGUST 1900 OBSERVATIONS.

Changes in the apparatus.—In the second summer's work, the heliostat which had been the cause of so much annoyance was replaced by the heavily mounted coelostat used by the Yerkes Observatory party in the May 28, 1900, eclipse observations at Wadesboro, N. C. The coelostat was driven by the clock of the 12-inch Kenwood telescope. The same plane mirror earlier used on the heliostat was resilvered and mounted on the polar axis of the coelostat. The change to the coelostat made the use of an additional plane silvered surface necessary, to direct the beam to the 24-inch concave mirror. The position of this new vertical plane mirror depended upon the declination of the star observed. The arrangement of the mirrors is schematically shown in Fig. 4, in which *C* represents the coelostat, *F*, the approximate position of the vertical flat in the *Jupiter* and *Saturn* observations, and *F'*, its relative position for *Arcturus*. The lettering of the remaining parts of the diagram corresponds to that in Fig. 3.

The remainder of the apparatus (Plate I) was mounted further back in the covered gallery than in the arrangement used in 1898. The use of selected commercial plate glass silvered had worked so well in the case of the heliostat mirror, that a plate 27×40 inches was chosen and mounted in an upright wooden frame, to be used at *F*. The observations on *Jupiter* of August 5, 6, 8, and 9, were made with its aid, although the images obtained were far from satisfactory, showing a marked astigmatism. This fault was so greatly increased, at the greater incidence necessary for the observation of *Arcturus*, as to render its employment out of the question. On meeting this difficulty, Director Hale kindly put at my disposal a fine 24-inch circular flat mirror, freshly silvered and very perfectly figured by Mr. Ritchey. This mirror was used in the subsequent measurements. The angle of incidence of the *Jupiter* beam from the coelostat upon this mirror was 29°, and the reflected beam filled only 96 per cent. of the aperture of the 24-inch concave mirror. A correcting factor of 1.04 was consequently to be applied to the heat measurements on *Jupiter* and *Saturn*, to reduce them to full aperture. In the observations on *Arcturus* an incidence angle of 57° occurred, and a consequent factor of 1.94 was used to reduce the observations to full aperture. Unfortunately, *Vega* was beyond the limited range of the new apparatus, so that no further measurements upon that star were possible.

The connection between the driving-clock and the coelostat axis was through a worm and driving sector. This was set for a small lost motion, the axis counterpoised, and a cord attached to a lever on the axis; thus, by pulling the cord sharply, the axis and the mirror attached to it could be rotated through an angle equal to the lost motion. In this way the star image was easily and promptly thrown on and off the radiometer vane by the observer at *T′*. This device worked faultlessly.

From the summer of 1898 the radiometer had stood undisturbed, in the position where it had been earlier used. It was necessary to open the case to recoat the inside surface with lampblack, and by an unfortunate accident in entering the case,

the fiber of the suspension was broken. A new fiber was attached, and the blackened surfaces of the vanes marred by the accident, were repaired. Several days were spent in equalizing the two vanes so that the compensation was much more complete, and the instrument was steadier in its action than before. The new fiber proved to be slightly finer than the old one, so that the period was raised from 10 or 11 to 13 seconds, and the sensitiveness correspondingly increased. The radiometer used under the new conditions was much more efficient than before.

Sensitiveness of the apparatus.—The sensitiveness in the different series of observations ranged between 9.9 and 12mm for the heat from a candle 811 cm distant, after one reflection. The averages of the various series are given as they were observed, and the probable error computed as already described. A deflection of 11 mm (the average sensitiveness) for a candle 811 cm distant, would mean a deflection of $11 \times (8.11)^2 = 724$, for a candle one meter distant. Taking into account the ratio of the surface of the radiometer vane to the effective aperture of the mirror, 1:94968, we have 68750000. A deflection of 1 mm would be caused then by $\frac{1}{68750000}$ of the heat received on a surface equal to the aperture of the concave mirror, from a candle 1 meter distant. If the averages are to be expressed in terms of the unit 10^{-8} meter candle, they must be reduced to a sensitiveness corresponding to 16 mm for a candle at a distance of 811 cm. The two years' observations will then be reduced to the same unit.

Sensitiveness of the apparatus and atmospheric absorption.—Although the processes by which the above equivalence of a 1 mm deflection to the $\frac{1}{68750000}$ part of the heat from a candle 1 meter distant, when concentrated by the 24-inch concave mirror, seemed legitimate, still no allowance was made for the reflection on two additional surfaces. It was therefore desirable to make actual tests of the apparatus upon a candle at so great a distance that the radiometer sensitiveness could be determined, so far as possible, in connection with the same mirrors used in the star observations. In such a test, it was plain that the

absorption of a long layer of intervening air would be unavoidable. In order to obtain a correction factor for this absorption, it was decided to establish two stations at different distances from the Observatory.

From the parapet of the heliostat gallery, the ground with very slight undulations stretches away to the westward for several miles in nearly level fields of pasture and cultivated ground, with no intervening trees or objects to obstruct the view (Fig. 6, Plate II). From the base of the parapet some 25 feet below, a line was run due westward, and a distance of 2000 feet chained off. At this point the first station was established, and the same line continued 2500 feet further, or 4500 feet, from the parapet, where the second station was located (Fig. 5, Plate II). A tent was set up at each station, and inside each, a wooden box mounted four feet or more from the ground on stakes. Vertical slits 2½ inches wide, and a foot or more long, were cut in the boxes on the side toward the Observatory. The boxes were otherwise well ventilated, so that a candle placed inside burned quietly with a flame of normal height. At first the slits were provided with light shutters which could be raised and lowered by the drawing of a cord by an assistant at a considerable distance from the box. It was found, however, that moving the shutter, with no candle in the box, often caused a small deflection. It was therefore decided to stand the candle on a small sliding carriage on the floor of the box, by which it could be drawn up behind the opening, or allowed to slide to one side of the slit, so that the wall of the box concealed it. It was found that moving the candle back and forth produced no deflection when the candle was not lighted, nor did it seriously disturb the flame when lighted.

FIG. 7.
(2½ times natural size.)

From the parapet the line of sight to the further tent passed directly over the nearer tent. The 24-inch flat mirror *F*, Fig. 4, was turned until its plane lay N. W. and S. E., and so adjusted that the whole of the reflected beam fell on the 24-inch concave

PLATE II.

FIG. 5.
TAKEN WITH TELEPHOTO LENS.

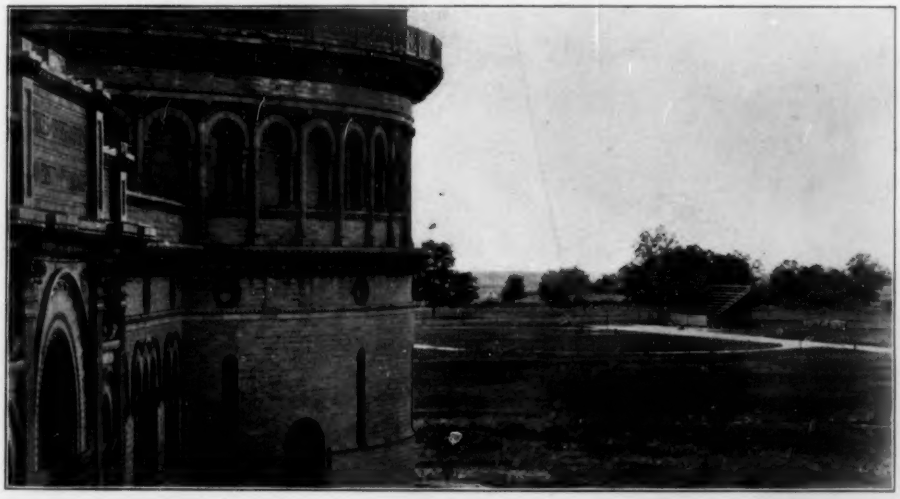


FIG. 6.
STATIONS FOR MEASURING ATMOSPHERIC ABSORPTION.
Distances from Observatory: 2000 feet and 4500 feet.

mirror, which formed an image of the candle in the box of the nearer tent upon one of the radiometer vanes (Fig. 7). The coelostat mirror was not used in these measurements. The candle heat suffered three reflections before entering the radiometer, as in the 1898 star heat measures, instead of four, as in the case of the 1900 measurements. The image of the candle in the box in the further tent could easily be brought upon the vane by slipping a small wedge into the space between the frame carrying the mirror *F*, and its support behind it, to which it was hinged at the top.

It was found that the air layer along the ground, which transmitted the radiation from the candles in the two tents, was so disturbed during the day that it was necessary to make the measurements at night; and even then the radiometer was less quiet than when the mirrors faced the sky, as in the star measures.

In making the observations one of the observers stationed himself at the nearer tent, lighted and trimmed the candle, and then, with cord in hand, withdrew to such a distance that, though he could watch the candle, his own image could by no possibility be reflected into the radiometer. A box, with the shutter facing the tents, was placed on the parapet of the heliostat gallery with a lighted lantern inside to serve as a signal to the man in the tent. A cord which operated this shutter was carried in to the observer at the radiometer. When all was ready he drew this cord, which exposed the lantern to the assistant in the tent, who replied by exposing the candle so that its image fell upon the radiometer vane. When the suspension had reached the extreme of its first swing, the lantern shutter was dropped as a signal to conceal the candle in the tent. After a satisfactory series of measurements had been obtained for the candle in the nearer tent, the assistant was signaled to go to the further tent, where the same procedure was followed until a satisfactory series had been obtained from that station. On the way in from the further tent, a second series of measurements was made on the candle in the nearer tent. By this method measurements on the

heat of one candle at a distance of 633.6 meters, and on the heat of two candles at a distance of 1396 meters from the 24-inch concave mirror, were made on August 26 and 27. The series obtained on each of these two evenings showed such large fluctuations in the transmission of the atmosphere as the night advanced, that in each case the mean of the first and last series in the near tent could hardly be depended upon to represent the atmospheric conditions during the middle series in the further tent. On August 29 it was decided to make three series of observations in as rapid succession as possible from the nearer tent, and in between, two from the further tent.

Professor St. John stationed himself at the further tent and Mr. Ellerman at the nearer one. The observations were made as rapidly as possible. The results for the three evenings' observations on candles in the two tents were as follows:

Date	Heat of 2 candles at 1396 meters / Heat of 1 candle at 633.6 meters
August 26	19.3 per cent.
August 27	25.0 "
August 29	20.2 "
Mean	21.5 per cent.

If there had been no loss by atmospheric absorption the ratio, according to the law of inverse squares, should equal $\frac{2(633.6)^2}{(1396)^2}$ $= 41.2$ per cent. The mean transmission of candle heat of an air layer of 762.4 meters along the ground, for the three evenings, is thus $\frac{21.5}{41.2} = 52.3$ per cent. Applying the general absorption equation, in which I equals the original intensity and a the absorption of a unit layer, the intensity after traversing n such layers will be $I(1-a)^n$. Taking 100 meters as the unit layer, and calling the original intensity 1, we have $(1-a)^{7.62}$ $= 0.523$; whence $a = 0.081+$, or the transmission of 100 meters $= 0.918$.[1] In connection with his study on the temperature of

[1] It will appear from this transmission coefficient that an air layer along the ground, 250 meters in length, will absorb as large a percentage of the total radiation from a candle as the percentage of starlight absorbed by the depth of the whole

the Moon, Professor Langley[1] measured the transmission of an air layer of 100 meters along the ground for rays from a large blackened Leslie cube filled with boiling water. The measurements on four different evenings in June and August gave absorptions varying between 14.6 per cent. and 32.9 per cent., depending on the quantity of precipitable water in the air. The extreme range of absorption noted in the case of the present measurements occurred between the two series of observations made the evening of August 26 on the candle in the near tent. The first series was made at 8:30 P. M.; the second at 10:30 P. M. During this interval the temperature fell from 68° Fahr. to 60°, accompanied by the formation of an unusually heavy dew. The mean deflection of the earlier series was 36 mm; of the later, 92 mm. The average absorption given above for 100 meters corresponds to a deflection of 61 mm, at the same sensitiveness, for a candle in the nearer tent.[2] Unfortunately for the comparison, it was not convenient to make any accurate determination of the precipitable atmospheric moisture in the foregoing measurements, but if the results can be taken to represent average conditions, it would appear that atmospheric absorption is less for the heat of a candle than for that from a black radiator at 100°[3]. The maximum in the energy curve of a black radiator at 100° was found by Langley to fall in the region of the spectrum corresponding to the greatest atmospheric absorption. Hence, the higher the temperature, the smaller will be the percentage of the whole emission lying in the region of these

atmosphere. In the course of the observations on the heat from a candle in the nearer tent, the absorption of a sheet of plate glass, held about six inches in front of the candle, was found to be 55 per cent. The absorption, by the same glass plate, of the heat from a candle in the same room with the radiometer was measured and found to be practically the same percentage as in the tent.

[1] S. P. LANGLEY, *Mem. Nat. Acad. Sci.*, Vol. IV, Pt. 2, p. 183.

[2] During a series of measurements on a single candle in the near tent made August 25, Professor St. John extinguished the candle and placed his head in front of the candle box at the signal, instead of exposing the candle. The uniform deflection obtained was 25 mm. The candle gave a deflection of 62 mm.

[3] It is possible that the absorption of the fluorite window may have exerted a small influence on the present measurements of atmospheric absorption.

wave-lengths, and the smaller the percentage of absorption by moist air for the total radiation. This raises a question pertinent to the present study, namely, the fallacy of using the same correction factor for atmospheric absorption in comparing two bodies of as obviously different energy spectra as *Arcturus* and *Vega*.

At the average sensitiveness (11 mm for the test candle 811 cm distant), the mean deflection for a candle in the nearer tent, 633 meters distant, was 67 mm. To correct for absorption $(.918)^{6.33} I = 67$, whence $I = 115$. The angle of incidence on the 24-inch circular flat mirror at *F*, Fig. 4, was 47°; consequently, the deflection, if the full aperture of the 24 in. concave mirror could have been employed, would have been $\frac{115}{\cos 47^\circ} = 169$ mm; whence the computed deflection for a candle 1 meter distant would be $169 \times (633)^2 = 67660000$ mm. This agrees very closely with the sensitiveness value, 68750000 mm deduced in the earlier computation. As there were two more reflecting silver surfaces in the path of the beam in the latter than in the former case, the value ought to have been 6 or 7 per cent. smaller. The discrepancy may have been due to error in measuring the diameter of the radiometer vane, which was given as 2 mm. A diameter of 1.94 mm would make the ratio of surface of vane to surface of 24-inch concave mirror enough larger than 1 : 94968 (the value adopted in the previous calculation) to bring both values into agreement.

The sensitiveness of the radiometer and radiomicrometer compared. —We now have a double means for comparing the sensitiveness of the radiometer with that of the radiomicrometer used by Professor Boys, which gave a deflection of 60 mm for a candle 152 cm (60 in.) distant. This corresponds to a deflection of 1.7 mm for a candle at a distance of 811 cm. The radiometer under these circumstances gave a mean deflection of 11 mm. The ratio of the area of the receiving service in the radiomicrometer to that of the radiometer was as $4 : \pi$. The ratio of the effective sensitiveness would thus be $1.7\pi : 4 \times 11 = 1 : 12+$. In other words, the radiometer was 12 times as sensitive as the radiomicrometer.

The radiomicrometer was used with a concave reflector of 16 in. diameter; the radiometer with one of 24 in. diameter. The ratio of the respective apertures is as 1 : 2.2. Thus the radiometer combined with its mirror wherever the full aperture could be utilized, was over twenty-six times as sensitive as the apparatus used by Professor Boys. The sensitiveness of the two sets of apparatus may be roughly compared as they were used on the stars, by comparing the deflection of 38 mm., which Professor Boys obtained from a candle 229.2 meters (250.7 yards) distant, with the deflection of 67 mm obtained by the present apparatus for a candle 633 meters away, using only two thirds of the aperture of the condensing mirror. Assuming the average transmission coefficient for a 100 meter air layer and deducing from it the deflection for a candle 1 meter from the 16-inch concave mirror, the value 1923000 mm is obtained. As compared with the corresponding deflection of 67000000+ mm, the advantage in sensitiveness of the radiometer over the radiomicrometer comes out in the ratio of 35 to 1. The uncertainty of the atmospheric absorption in Professor Boys' measurement makes this result of no value except as a rough check upon the earlier computation of the sensitiveness ratio. It may be further added that with the telescope and scale method employed in measuring the radiometer deflections it was possible to read to the tenth millimeter while Professor Boys attempted no closer estimation than to a fourth millimeter. The small amounts of heat detected from *Jupiter*, *Arcturus*, *Vega*, and *Saturn* with the present apparatus readily accounts for the negative results of the radiomicrometer measurements. With no atmospheric absorption, the number of candles in a group at a distance of $\sqrt{680000000} = 26000$ meters (about 16.2 miles) could be determined by the mean of a series of measurements. Using the atmospheric absorption for 100 meters given above, we have the formula $\frac{680 \times 10^6 \times 0.981^n}{(10n)^2}$ for computing the distance in kilometers along the ground at which the number of candles in a group could be thus determined. For $n = 43$, or a distance of 4.3 kilometers, each candle would

give a deflection of only 0.1 mm, the smallest recognizable deflection. About 2.7 miles along the ground then, would be the practicable limit of measurement for the heat from a single candle.

Changes in the method of observing.—The method of making the observations was but slightly changed from that already described under the 1898 observations. As the coelostat was more easily managed to bring the star image on and off the radiometer vane, the observer at T' (Fig. 4) was less constantly occupied with his work, so that, to still further remove the effects of prejudice on the part of the observer who read the deflections, he took over the work of recording the observations as well. When the radiometer suspension had come to rest, the observer at T gave a signal to shift the star image. The recorder changed the image and counted slowly up to seven. The counting was found to involve a period slightly under seven seconds. At the seventh count the deflection was read aloud to the recorder, who entered it with a sign to indicate to what change on his part the deflection corresponded. He often made the same change over and over, such as throwing the image on the same vane several times in succession instead of throwing it first on, and then off at the next signal. The observer at T might as well have been a strip of photographic paper, so far as any knowledge of the significance of what he was reading was concerned. His only chance to use judgment was to decide when the index was quiet enough to risk a deflection.

Character of the nights on which measurements were made.—August 5. Sky thick and white; light wind. Series on *Jupiter*. E. F. N., observer; C. E. St. J., recorder.

August 6. Sky same as on preceding night; no wind. Series on *Jupiter*. E. F. N., observer; C. E. St. J., recorder.

August 8. Sky thick; light clouds forming and dissolving constantly; light breeze. Series on *Jupiter*. E. F. N., observer; C. E. St. J., recorder.

August 9. Sky hazy; later developing light cirrus clouds in

neighborhood of *Jupiter*. No wind. Series on *Jupiter*. E. F. N., observer; C. E. St. J., recorder.

August 10. Sky more transparent than on previous evenings, but not brilliant. Series on *Arcturus*. E. F. N., observer; C. E. St. J., recorder.

August 13. Sky clearer than on previous night. Series on *Arcturus* and *Jupiter*. E. B. Frost, observer; E. F. N., recorder.

August 14. Sky only fairly transparent; lightning in west and southwest; conditions disturbed and radiometer unsteady. Series on *Arcturus* and *Jupiter*. Latter cut short by clouds. E. F. N., observer; C. E. St. J., recorder.

August 15. A brilliantly transparent sky after dissipation of clouds in early evening. Series on *Jupiter*. G. E. Hale and H. M. Goodwin, observers; C. E. St. J., recorder.

August 18. Thick sky; fairly uniform in early evening; increasing in transparency later. Series made on *Arcturus*, *Jupiter*, and *Saturn*. E. F. N., observer; C. E. St. J., recorder.

August 19. Very transparent sky. Series made on *Arcturus*, *Jupiter*, and *Saturn*. E. F. N., observer; C. E. St. J., recorder.

August 26. Measurement of atmospheric absorption by observations on candles in distant tents. Early part of evening partly cloudy. Lantern signals on Observatory parapet, as seen from tents, showed marked twinkling. Atmospheric conditions improved steadily during progress of observations and at close sky was unusally transparent. At beginning, wet bulb thermometer 67° and dry bulb 68°.8 F. At close, wet bulb 60°, dry bulb 60° F., at nearer tent six feet from ground. Air free from dust.

August 27. Observations of previous evening repeated. Night began transparent, but later thickened. Candle in further tent appeared noticeably redder than candle in nearer tent. At beginning, dry bulb 70°, wet bulb 67°.5; at close, dry bulb 69°, wet bulb 67°.3. No dust in air.

August 28. Sky transparent, very steady and uniform throughout the evening. At close of last series heavy fog began to rise from ground. Series on *Jupiter* and *Saturn*. C. E. St. J., observer; E. F. N., recorder.

August 29. Night dry and clear; no dust; very light dew. Measurement of atmospheric absorption by observations on candles in distant tents.

The tables.—The headings of the columns of the tables which follow have the same signification as in the tables of the 1898 observations, except that in the next to the last column the values, in addition to a reduction to 10^{-8} meter candle, have also been reduced to the full aperture of the mirror. No such correction was necessary in the 1898 measurements, because the heliostat reflected a beam large enough to fill the whole aperture of the 24-inch concave mirror.

The first four series on *Jupiter*, August 5, 6, 8, and 9, were made with a defective mirror at *F*, which gave very badly distorted images, so that it is doubtful whether all of the heat which should have reached the concave mirror was concentrated on the vane; hence a heavy line is drawn in the table separating these values from those that follow.

TABLE IV.

JUPITER. AUGUST 1900.

Date	Time P.M.	"On" obs.		"Off" obs.		No. neg. obs.	Combined average		Sens.	Sens. 10^{-8} meter candle	Zenith dist.
		No.	Av.	No.	Av.						
5	8.35–9.30	19	0.30 mm	23	0.54 mm	12	0.42 mm	± 0.08	10.7	0.63	69° 40′
6	8.40–9.30	10	0.21	10	0.73	5	0.47	± 0.16	10.0	0.75	70° 20′
8	9.05–9.45	17	0.22	12	0.57	10	0.40	± 0.11	11.9	0.55	73° 10′
9	7.35–8.30	15	0.31	15	0.57	8	0.44	± 0.08	12.2	0.53	67°
13	9.10–9.30	11	0.64	11	0.45	6	0.55	± 0.15	9.9	0.92	74° 50′
14	9.00–9.15	7	1.0	8	0.2	2	0.60	± 0.11	11.1	0.89	73° 50′
15	8.55–9.25	15	1.29	15	1.20	0	1.25	± 0.05	12.2	1.70	74° 40′
18	8.45–9.17	14	0.80	12	1.05	1	0.93	± 0.07	11.2	1.58	74° 50′
19	8.52–9.30	13	1.08	13	1.22	3	1.15	± 0.15	10.2	1.87	76° 30′
28	8.03–8.30	11	1.35	11	1.43	0	1.39	± 0.11	11.9	1.93	74° 10′
										Mean	75°

TABLE V.

ARCTURUS. AUGUST 1900.

Date	Time P.M.	"On" obs. No.	"On" obs. Av.	"Off" obs. No.	"Off" obs. Av.	No. neg. obs.	Combined average	Sens.	Sens. 10^{-8} meter candle	Zenith dist.
10	8.00–8.30	16	0.61 mm	16	0.42 mm	10	0.51 mm ± 0.09	10.9	1.45	55° 50′
13	8.10–8.50	14	0.13	14	0.52	8	0.32 ± 0.09	9.9	0.99	55° 50′
14	7.50–8.45	15	0.04	16	0.46	11	0.25 ± 0.11	11.1	0.70	52° 20′
18	7.45–8.18	17	0.45	18	0.34	11	0.38 ± 0.09	11.2	1.06	51° 40′
19	7.55–8.35	11	0.73	12	0.03	9	0.38 ± 0.12	10.2	1.15	55° 40′
									Mean	54°

TABLE VI.

SATURN. AUGUST 1900.

Date	Time P.M.	"On" obs. No.	"On" obs. Av.	"Off" obs. No.	"Off" obs. Av.	No. neg. obs.	Combined average	Sens.	Sens. 10^{-8} meter candle	Zenith dist.
18	9.35–10.15	16	0.09 mm	16	0.27 mm	10	0.18 mm ± 0.13	11.2	0.27	71° 30′
19	9.50–11.00	19	0.20	16	0.02	15	0.11 ± 0.10	10.2	0.18	74° 30′
28	8.40– 9.30	19	0.20	18	0.15	13	0.17 ± 0.09	11.9	0.24	70° 10′
									Mean	72°

To test the method, after the series on *Saturn*, August 28, the coelostat was turned back a short distance in right ascension, so that the field in the radiometer was a patch of uniform bare sky. The coelostat was then oscillated back and forth, in the same manner in which the star image was thrown on and off the radiometer vane, and the deflections were read with the same care. The result of a series of twenty-five observations is given below.

No. "on" obs.	Av. "on" obs.	No. "off" obs.	Av. "off" obs.	Comb. av.	Sens.
12	−0.12	13	0.15	0.05 ± 0.12	11.9

There was a heavier drift than usual during this series, so that the averages of the "on" and the "off" observations were contradictory, both indicating a deflection in the *same* direction instead of in *opposite* directions. One set, therefore, had to be interpreted negatively, giving the above combined average.

Two series are given below copied entire from the Observatory notebook, which show the deflections in the order in which they were observed. Of the two series, the one on *Jupiter* is one of the best, and the one on *Saturn* among the worst, obtained. *o*, indicates star image thrown on the vane; *f*, image thrown off the vane.

August 15. *Jupiter:* image on right vane of radiometer. G. E. Hale and H. M. Goodwin, observers, C. E. St. John, recorder. 8:55 P.M.

	Cont.	Conclu.	
f+1.5 mm	*f*+1.2	*f*+0.3 against drift	
o−1.4	*o*−1.6	*o*−1.2	
o neg.[1]	*f*+1.5	*f*+1.3	
f+1.1	*o*−1.7	*f*+1.1	
o−1.3	*f*+0.8	*o*−1.5	
f+1.5	*o*−1.2	*f*+1.4	
o−0.5	*f*+0.8 against drift	*f*+1.6	
o−1.2	*o*−1.2	*o*−1.9	
o−1.2	*o*−0.7	*f*+1.7	
f+1.2	*f*+0.9	*o*−1.8	9:25 P.M.

o negative and *f* positive indicate heat.

August 18. *Saturn:* image on left vane of radiometer. 9:35 P.M. E. F. N., observer, C. E. St. J., recorder.

	Cont.		Conclu.	
f+0.3 mm	*f* pos.	Radiometer	*f*−1.1	
o−0.4 first to −1,	*o*−1.9	much	*f*−1.9	
f−0.7	*f*−0.2	disturbed	*f*−1.0	
o+0.8	*o* pos.		*f*−0.4	
f−0.4	*o*−1.0		*o*−1.1	
o+1.9	*f*+1.5		*o*+1.4	
f+1.8	*o*−1.2		*o*−1.4	
o+0.5	*f*−0.2		*f*−0.3	
f−0.1	*o*+0.6		*o*+0.0	
o−0.5	*f*−0.8		*o*+1.1	
	f+0.9		*o*+1.2	
	o+0.6		*f*−1.7	10:15 P.M.

f, negative and *o*, positive indicate heat.

[1] "Neg. or pos." indicate a deflection of more than 2 mm in the negative or positive direction.

RESULTS.

Table VII displays all the results thus far obtained, with the exception of the four doubtful series on *Jupiter*, reduced to 10^{-8} meter candle with no correction for atmospheric absorption.

The very close agreement between the means of the two sets of observations on *Arcturus* cannot but be accidental, for one high or one low value, more or less, in either series, would completely upset the coincidence. No correction has been applied to the 1900 observations in comparing them with those of 1898, on account of the one additional reflection in the 1900 series.

TABLE VII.

Date 1898	*Vega*	*Arcturus*	*Jupiter*	*Saturn*	*Arcturus* / *Vega*
Aug. 3	0.55				
4	0.33	0.65			2.1
5		1.06			
7		1.60			
8	0.64	1.30			2.0
9	0.33	0.98			3.0
11	0.60	1.36			2.3
12	0.50				
13	0.68	0.68			1.0
Means	0.52	1.09			2.1
1900					*Jupiter* / *Arcturus*
Aug. 10		1.45			
13		0.99	0.92		0.93
14		0.70	0.89		1.3
15			1.70		
18		1.06	1.58	0.27	1.5
19		1.15	1.87	0.18	1.6
28			1.93	0.24	
Means		1.07	1.48	0.23	1.33

Reduction of the observations to the zenith. Final results.— In comparing the heat effects of planets and stars at such widely different zenith distances as 14° and 75°, some correction for the differences in atmospheric absorption in the two positions ought obviously to be applied. I have tried to find trustworthy

pyrheliometric or actinometric measurements of the solar constant for high and low Sun, made at some station about 1000 feet above the sea (an altitude corresponding to that of the Yerkes Observatory), but so far have not succeeded.

Müller's[1] photometric extinction coefficients for Potsdam correspond well so far as concerns altitude, but they do not take account of energy outside of the visible spectrum. From observations made at Allegheny and Mt. Whitney, Langley[2] finds that the atmosphere lets through infra-red wave-lengths in greater proportion than visible rays, except in the region of the infra-red cold bands, where very heavy absorption occurs. The same experiments show that there is a considerable fluctuation in the diathermancy of the atmosphere with the seasons, absorption being greatest in the summer and least in the winter. The whole matter of zenith reduction is unsatisfactory, because tables must be made out for an abstraction called "an average night." As the range of atmospheric diathermancy for nights which can be called clear is at least as great as one to two, it is only at rare intervals that a strictly average night is to be had, and then average conditions maintain for an hour or two at most. One cannot be sure that the mean of four, five, or even a greater number of nights, will represent these average conditions. Further, as has already been pointed out, stars of different types at the same zenith distance for simultaneous observations ought not, in strictness, to have the same reduction factor applied. Some of these considerations, however, involve refinements beyond the accuracy of the present measurements, and under the circumstances there is no choice but to apply Müller's coefficients in the zenith reductions.

The correction for *Vega* is so small that the values in Table VII may be taken as zenith values. Table VIII shows the relative intensities of the means expressed in 10^{-8} meter candle, after the zenith reductions have been made. Because of the

[1] G. MÜLLER, *Photometrie der Gestirne*. Leipzig, 1897.

[2] S. P. LANGLEY, "Report on Mt .Whitney Expedition," *Sig. Serv. Profess. Papers*, 15, p. 211.

variation in atmospheric absorption, the averages in Table VIII were made up from series gathered on nights when at least two of the bodies compared were observed.

TABLE VIII.

Vega	*Arcturus*	*Jupiter*	*Saturn*
0.51	1.14	2.38	0.37

Thus the thermal intensity of:

Vega: *Arcturus*: *Jupiter*: *Saturn* :: 1 : 2.2 : 4.7 : 0.74.

The ratio of the zenith photometric intensities is:

Vega: *Arcturus*: *Jupiter* :: 1 : 1 : 7.8.[1]

The ratio greater than 2 to 1, of the total radiation of *Arcturus* to that of *Vega* (stars which by most observers are estimated to be of nearly equal photometric magnitude) indicates a proportionately more intense infra-red spectrum for the former than for the latter star. The greater intensity of *Arcturus* in the infra-red may be accounted for in two ways. The photosphere of *Arcturus* may be at a lower temperature than that of *Vega*, but the star be of sufficiently greater angular diameter, as seen from the Earth, to equal *Vega* in light intensity and surpass it in total radiation. This would be, without doubt, the first explanation to suggest itself. Recently, however, Sir William and Lady Huggins[2] have brought forward evidence to show that the photospheres of solar type stars are actually hotter than in stars of the first type, and that the color difference is due to the absorption of the stellar atmosphere, which, in solar stars, is denser and further developed. If this theory of Sir William and Lady Huggins be accepted, it will not be necessary to assume a greater angular diameter for *Arcturus* than for *Vega* to explain the present results.

The thermal intensity of *Arcturus* to *Jupiter* is 1 : 2.2, while the light ratio is 1 : 7.8. So far as the present results are trustworthy, this may be explained in any one or more of three ways: an infra-red spectrum of great extent and intensity for

[1] The photometric intensity of *Jupiter* for August 18, 1900, was computed from Müller's value for a mean opposition (*loc. cit.*, p. 384).

[2] *Atlas of Representative Stellar Spectra*, London, 1899, p. 79 *et seq.*

Arcturus; a comparatively low temperature of the outer envelope of *Jupiter;* or a strongly selective albedo for *Jupiter* in the infra-red.[1] That *Jupiter* emits no light rays is rendered probable by the fact that Professor Barnard[2] was unable to follow any of the satellites into the planet's shadow, even with the light-gathering power of the 36-inch Lick telescope.

In an endeavor to further test the matter, the transmission of *Jupiter* rays through a piece of plate glass 3.4 mm thick, was measured in connection with the other heat measurements. The plan followed was to take a series of eight or ten deflections on *Jupiter*, then take about the same number through the glass, repeat the first set, and so on. The dates of the observations, together with the transmission percentages and probable errors, follow.

August 9, 70 ± 3 per cent. August 19, 77 ± 9 per cent. August 28, 78 ± 3 per cent.

Of these values the last is the most, and the first the least, trustworthy.

The transmission of the same plate for various sources of heat follows in Table IX.

TABLE IX.

TRANSMISSION OF GLASS PLATE 3.4 mm THICK.

Source	Per cent.	Remarks
Leslie cube 100°	0	Or at least less than 1 per cent.
Candle flame	40	
Full Moon	48	
Jupiter	75	Zenith distance, 75°.
Sun	80	Zenith distance, 59°.

The very high transmission obtained for the Moon, as compared with the results of Langley,[3] Lord Rosse[4] and Boys,[5] is

[1] Any error attributable to the zenith reduction is wholly inadequate to account for the discrepancy between the ratios of the thermal and photometric intensities.

[2] E. E. Barnard, *Astr. Nachr.* Bd. 144, No. 3453, p. 330.

[3] S. P. Langley, *Mem. Nat. Acad. Sci., loc. cit.*

[4] Lord Rosse, *Phil. Trans.*, 1873, II, p. 587.

[5] C. V. Boys, *loc. cit.*

easily explained because a very large part of the Moon's emission was shown by Langley to consist of wave-lengths greater than 9μ, which were stopped under all circumstances by the fluorite window. It was impossible to work with the Moon's image on either vane of the radiometer alone because the heat violently drove the suspension beyond the scale, but the image was thrown on both vanes and the radiometer used differentially. The high transmission of *Jupiter* rays, and its close resemblance to the solar transmission, is in part doubtless explicable by *Jupiter's* abnormally high albedo, which is more than 4.5 times that of the Moon; yet there seems to be surprisingly little heat radiation present, such as a candle or Leslie cube sends out; *i. e.*, heat rays in large part stopped by the glass and let through by fluorite.

The results of a study, soon to be undertaken, to investigate the absorption spectrum of the glass plate, will give added definiteness to any conclusions to be drawn from these observations concerning the temperature of *Jupiter's* outer envelope.

MINCHIN'S EXPERIMENTS.

In a preliminary paper before the Royal Society, Professor G. A. Minchin[1] described a very interesting series of experiments on the effect of radiation from the stars on a photo-electric cell of special construction, used in connection with a very sensitive electrometer. The action of radiant energy on the cell is such that the electric potential and the electrometer deflection increase as the square root of the incident intensity. Fortunately for a comparison of Minchin's results with those presented here, he used the sensitive surface of the cell in the focus of a 24-inch concave mirror. A part of Minchin's results are given in Table X.

TABLE X.

Object	Deflection d	Energy $\propto d^2$
Arcturus	8.2 mm	67.
Saturn	5.6	31.
Vega	11.5	132.
Candle ten feet away	10.0	100.

[1] G. A. MINCHIN, *loc. cit.*

Thus *Vega* shows half again the intensity of *Arcturus*, and more by a third than a candle ten feet away (presumably without concentration by the 24-inch mirror). Were the above intensities proportional to the total radiant energies received from the bodies compared, the radiometer at average sensitiveness should have given a deflection of 100 mm for *Vega* instead of the bare ¼ mm observed. It would appear, therefore, that the photo-electric cell is not sensitive in the infra-red spectrum.

INSTRUMENTAL REQUIREMENTS FOR FURTHER EXPERIMENTS.

The object for which the present study was primarily undertaken has been in a measure realized in gaining more or less trustworthy estimates of the heat from four stars and planets. Although the results so far gained can be considered only in the roughest sense quantitative, they indicate a way to a more extensive knowledge of the heat radiation of the brighter stars, by supplying a basis upon which the requisite apertures of condensing mirrors may be computed and by suggesting further refinements in the radiometer. A concave mirror five feet in diameter would possess a gathering power more than six times that of the two-foot mirror used in the present work, and with a suitably modified Coudé mounting, such a mirror could be effectively employed, even with no greater radiometric sensitiveness than that already realized. By its aid white stars down to the second magnitude, and red stars possibly to the third, could be arranged in the order of the thermal intensity of their radiations. It ought also to be possible to study roughly the distribution of energy in the spectra of stars like *Sirius*, *Arcturus*, *Capella*, *Vega*, and possibly others.

Wien's[1] law of the distribution of energy in the spectrum of a black body furnishes the relation $\lambda_{\max} T =$ const. (in which $\lambda_{\max}$ is the wave-length of the maximum energy in the spectrum, and T the absolute temperature) which, applied even to crude determinations of energy distribution in stellar spectra, should

[1] W. WIEN, *Ber. d. Berl. Akad.*, 1893.

afford rough estimates of stellar temperatures.[1] The radiations from stars which reach the Earth have, however, suffered selective absorption and selective reflection or scattering in traversing first the gaseous envelope of the star and later our own atmosphere. The studies of Langley, and others, have afforded some knowledge of the distribution of this kind of absorption in the Earth's atmosphere, and later work will doubtless make this knowledge more definite. But it is in dealing with the absorption of the stellar atmosphere that the greatest ultimate difficulty is to be expected. Wherever any considerable selective absorption or scattering exists in the atmosphere about the star, a determination of the wave-length of the maximum of the initial energy can be at best but uncertain, and the formula, which would be of comparatively easy application to the blue-white stars, because of their supposed small selective absorption, will not so aptly apply to stars belonging to other groups. This difficulty has already been dealt with in the problem of the Sun,[2] but in this case, in addition to being able to measure rays from different portions of the Sun's disk, we have such abundant energy to work with that the study of any desired number of isolated portions of the Sun's spectrum can be undertaken. In the case of the brightest stars and five-foot apertures, on the other hand, the whole stellar spectrum could not be divided into more than five or six regions for such a study. The problem will consequently be vastly more difficult and uncertain. That no very close approximation to the true stellar temperature of yellow and red stars is to be hoped for by this method is very plain, although the knowledge of the Sun already gained might be applied to stars of the solar type.[3] Approximations to the effective temperatures, though necessarily interpreted between rather wide limits, will be serviceable so long as no better are available. It

[1] This statement assumes that a stellar photosphere may be regarded as a "black body," a fact which, although doubtless approximately true, has as yet (so far as the writer is informed) received no direct confirmation.

[2] J. SCHEINER, *Strahlung und Temperatur der Sonne*, Leipzig, 1899.

[3] Compare J. SCHEINER, *loc. cit.*, pp. 39 and 60.

is well to remember in this connection how recent are any concordant results concerning the solar temperature, although the fault here is attributable to the lack of any trustworthy law of radiation.

Could stellar temperatures be roughly determined, approximate values of the relative angular semi-diameters among stars of the same spectral type might be computed in accordance with Stefan's law. It will be not without interest, in a later paper, to use the present material for an estimate of the angular semi-diameter of *Arcturus*, as follows: The relation of *Arcturus* to a candle has been measured and the same comparison can be made between a similar candle and the Sun at the same time of year. Assuming that the total radiant intensity of unit area of *Arcturus*, E_a, is not greatly different from that of the Sun,[1] E_s; and if θ_a represent the angular semi-diameter of *Arcturus* and θ_s that of the Sun then, $\theta_a = \theta_s \sqrt{\frac{E_a}{E_s}}$. Further, if D_a and D_s represent the distances of *Arcturus* and the Sun, and V_a and V_s their respective volumes, then $V_a = V_s \left(\frac{E_a}{E_s}\right)^{\frac{3}{2}}$. In the latter equation I believe it is safe to assume that the probable error in D_a is likely to be as large as that of the thermal quantities involved.

Considering the possibilities of a large reflecting telescope of the Coudé type in the photography of the fainter nebulæ and star clusters, and in the photography of star spectra, as well as its use in measurements of star heat, and many other astrophysical researches where laboratory conditions are essential, it is safe to predict that the addition of such an instrument to the equipment of one of our leading observatories would provide the means for solving a greater number of outstanding problems than the addition of any other single instrument which it is now possible to build.

Before closing I wish to acknowledge my widespread obligations to others for aid in the furtherance of the present study.

[1] The assumption of equality for total radiant intensity involves a smaller error than if an equivalence of luminous intensity had been assumed.

To Director George E. Hale I am indebted for the generous invitation to make use of the unique resources of the Yerkes Observatory for the foregoing experiments. I have received from him every possible assistance, the most valuable suggestions and advice, and have benefited by his most enthusiastic interest and coöperation. To my two assistants, Mr. A. L. Colton, formerly an assistant at the Lick Observatory, and Professor Charles E. St. John, of Oberlin College, I am indebted for many suggestions in dealing with the experimental difficulties which arose during the progress of the observations, and for skillful and patient assistance in the course of the measurements. I am, further, indebted to Professor Edwin B. Frost, and Messrs. G. W. Ritchey and Ferdinand Ellerman, for suggestions and assistance, and in some degree to every other member of the Observatory staff.

Dartmouth College,
January 24, 1901.

THE ATMOSPHERIC ABSORPTION OF THE VISIBLE RAYS, DETERMINED FROM SPECTROSCOPIC OBSERVATIONS OF THE EIFFEL TOWER ELECTRIC LIGHTS IN 1889.

By A. CORNU.

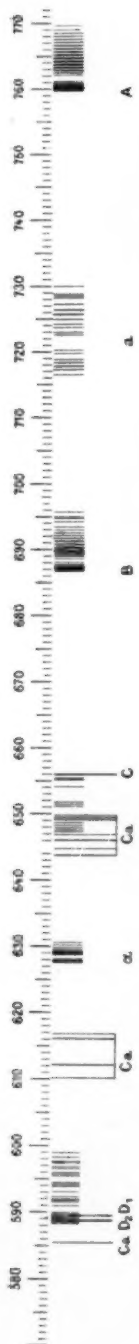
IT is natural to suppose that the terrestrial atmosphere would absorb in a horizontal direction the same rays and would produce the same spectral lines (the so-called *telluric* lines) that are observed in the solar spectrum. The existence of several telluric groups in the spectrum of an electric light projected from the Eiffel Tower to the Meudon Observatory has in fact been pointed out by M. Janssen,[1] and brought forward as a demonstration of the terrestrial origin of the A and B groups as well as of certain bands due to water vapor.

I undertook to carefully examine under high dispersion the series of dark lines visible in the spectrum of the electric lights at the summit of the tower, and to compare them with those that appear in the spectrum maps which I had previously published.[2] The observations also constituted a direct and valuable test of the *method of oscillating lines*, which had led me to distinguish between solar lines and those of terrestrial origin, in the most complicated groups of the solar spectrum.

The investigation was begun at the École Polytechnique, in the same place and with the same instruments which had been employed in my researches on solar spectroscopy. The observations were begun on October 24, 1889, with the aid of the light from one of the beacons at the summit of the tower, and were continued with one of the 90 cm Sautter and

[1] *Comptes Rendus*, **108**, 1035.

[2] "Sur les raies telluriques qu'on observe dans le spectre solaire au voisinage des raies D" (*Journal de l'École Polytechnique*, LIII, pp. 175–212, 1883). "Études des bandes telluriques α, B et A du spectre solaire." (*Annales de Chimie et de Physique* [6], 7, 5–102, 1886.)



Lemonnier search-lights, which M. Eiffel kindly caused to be directed toward the École Polytechnique between eight and ten o'clock, from October 27 to November 6, the day on which the Exposition of 1889 was closed and the search-lights extinguished. The distance from the tower to the École Polytechnique, as measured on a map of Paris of $\frac{1}{12500}$ scale, is about 4350 meters.

It was essential that the attendant in charge of the search-light should be able to recognize at once the point on the horizon toward which the light must be directed. For this purpose I had mounted near the window in the Pavillon des Elèves, where my instruments were installed, a large lens 24 cm in diameter and of 45 cm focal length; it was so adjusted during the day that the focal image of the highest gallery of the tower coincided with the central plane of the flame of a lamp, which was lighted at sunset and permitted the adjustments to be verified.

The reciprocity between the conjugate foci of the lens assured the projection of a beam of light which would cover the entire gallery with its battery of search-lights; the attendant in charge would thus perceive in the required direction an extremely bright disk, which could not possibly be confused with the scintillating points on the horizon. A red glass inserted near the flame rendered the distinction even easier.

I employed, according to circumstances, four spectroscopes, with increasing dispersion:

(1) A Duboscq direct-vision spectroscope with lateral scale.

(2) A Brunner goniometer, provided with two quartz prisms and quartz-fluorite objectives of 50 cm focal length, for photographing spectra.

(3) The same goniometer, provided with a flint prism and crown and flint objectives of 45 cm focal length.

(4) Finally, a large plane Rowland grating, observed with a collimator and telescope of 1 m and 1.40 m focal lengths respectively.

The collimator slit was illuminated by the image of the search-light of the tower, concentrated by an astronomical objective of 16 cm aperture and 2.30 m focal length.

The results fully corresponded with my expectations; during favorable evenings I was able to make a complete study of the telluric groups A, *a*, B, and D, at the outset with medium dispersion. But what seemed to me of the most importance was the possibility of using the great dispersion of the second order grating spectra; I succeeded in doing this several times, as is indicated in the résumé below of the results obtained each evening.

I should have wished to measure with the micrometer all the dark lines visible with this great dispersion; but unfortunately the sky became more and more hazy, the rain and fog constantly increased, and I could therefore only partially carry out this portion of my program, the settings becoming each day more difficult and more trying, because of the decreased intensity of the light.

Fortunately this long investigation turned out to be in large measure unnecessary, thanks to the characteristic configuration of the groups, which precisely reproduced those of my maps, so that a small number of settings sufficed to render certain their complete identification; this was precisely the end which I had in view.

RÉSUMÉ OF RESULTS.

I transcribe from the notebook the principal results obtained each evening:

October 24, 25, 26, 1889.—First observations with the Duboscq direct-vision spectroscope: a small collecting lens, then the 16 cm objective projecting the linear image of the tower light upon the slit.

Recognized and measured various bright lines of the metallic vapors in the electric arc (sodium, calcium, magnesium), as well as several dark lines, on the continuous spectrum of the carbons in the red part of the spectrum.

A comparison of these determinations with those made with sunlight during the day of the 27th shows that these dark lines correspond with A, *a*, and B (A and B are due to absorption by the oxygen of the air; *a* by water-vapor).

October 27.—Observed the beam from the 90 cm search-light. Brightness remarkable. A newspaper can easily be read by the light from the search-light. Brilliant spectrum. Collecting lens of 50 cm focal length. Observed many details in A, *a*, B, in the water-vapor lines near C and near D, which is double and reversed. Tried an experiment with the Rowland grating. Detected the flutings of B.

October 29.—Brunner goniometer. Flint prism (60°). 16 cm objective to concentrate the image of the search-light upon the slit. Measured on the divided circle the principal lines in the groups A, *a*, B, and several water-vapor lines near D; also several bright lines of calcium.

The brightness of the beam is so great that the Rowland spectroscope can be used. The two D lines (sodium vapor) are magnificent even in the second order: they are reversed at the middle and bright at the end. Near them can be observed all the water-vapor lines on my map (only the metallic solar lines are naturally absent): I examined them one by one in the first order.

I can also follow in detail the structure of the B group as far as the eighth doublet; beyond this the intensity is not great enough.

I had intended to measure all these lines with a micrometer; but I am so familiar with their arrangement, and the agreement with my map is so perfect, that I do not consider it worth while to lose time and tire my eyes in order to make these settings.

The α group (due to oxygen) is faint; its ordinary appearance is considerably modified by the intensity of the water-vapor lines which it contains: nevertheless it can be recognized. I can also detect the groups of water-vapor lines between B and C, which I have indicated as such on Fievez's atlas.

October 30.—The search-light is very bright. The B group is admirably seen in the second order. I can follow it to at least the 11th doublet, and can see the succeeding water-vapor lines, particularly the very strong line λ695 (λ6955.8 on my map). Verification of the water-vapor lines near C. Spent the entire evening in carefully identifying the α group, which is very faint and modified by the predominance of the water-vapor lines. I placed a micrometer wire on one of the characteristic lines of α; on the following day, at 2:50 P. M., I found with sunlight that it is certainly the line λ6276.8 of α on my map.

During the whole evening of October 30 the intensity of the light was so great that, without noticing it, I made all my observations in the second order, thinking it to be the first: the definition was so good that in the group near D I resolved the water-vapor line $\lambda 5922.6$ of my map.

October 31.—The sky is clearing; the air is growing cold and foggy; the image is not so bright as yesterday. Through the great kindness of the management the light from two projectors was sent to me simultaneously; but I could use only one of them, their angular separation being too great. The water-vapor lines are much less marked: they are almost altogether lacking near the two D lines. The α group, on the contrary, is much more easily seen. The B group is hardly visible in either the first or second orders. In spite of the increasing fog the violet lines H and K are visible with a Brunner goniometer, and even the ultra-violet band of carbon. The smoke of the electric power-house at the Place du Panthéon is very troublesome.

November 2.—Beautiful evening. Addition of a hydrogen Geissler tube to produce the C line as a standard in the field of the Rowland spectroscope. Verification of the water-vapor lines near C by comparison with this line and the bright lines of calcium.

α group very well seen; brightness sufficient to show as far as the fourth doublet of α and to permit settings to be made. Measured the distance between the strong line $\lambda 6276.8$ (oxygen) and the water-vapor line $\lambda 6291.4$ at the middle of the second doublet of α. Two measures gave 3.10 and 3.11 turns of the filar micrometer; on November 4 the same measure, made with sunlight, gave 3.105 turns: the identification is thus perfect.

The aqueous vapor group near D is admirably shown, exactly as on my map; I resolved $\lambda 5922.6$.

November 3.—Rainy evening; nevertheless the light is fairly bright. Attempted to photograph the more refrangible part of the spectrum. Brunner goniometer. Collecting lens of quartz-fluorite. Double quartz prism set at minimum deviation on the violet calcium line $\lambda 423$. Obtained ten violet and ultra-violet spectra on four gelatine plates, the exposures varying from 5 seconds to 2 minutes. No telluric bands. The plates show only the continuous spectrum of the carbons, the two bright carbon flutings, the bright lines H and K of calcium, the two intervening lines of aluminium, and a few others. Contrary to what one would have expected from the meteorological conditions, the ultra-violet spectrum is quite extensive and appears to stop at $\lambda 329$ only because of the absorption of the glasses which cover the aperture of the searchlight, and the defective reflection in the ultra-violet of the silvered concave mirror.

November 4—A little fog, and smoke from the Panthéon power-house. The water-vapor lines near D are once more clearly visible; micrometer settings for identification. Verified the existence of the water-vapor line $\lambda 5882.7$,

which almost exactly coincides with an iron line on my map and is rendered visible by the oscillation of the latter line. α group well seen, but no better than before. The B group is very beautiful when the slit is widened. Observed the water-vapor line λ6925.7 between the tenth and eleventh doublet and those which enclose the eleventh, *i. e.*, $\lambda\lambda$6928.1, 6928.3, 6928.9 on my map.

November 5—Rain all day; fog in the evening; the light appears very yellow. Nevertheless the red part of the spectrum is bright enough to permit me to make a long series of settings between B and C.

The thirty-four micrometer settings have been reduced to wave-lengths, using as standards the C line (λ6561.8) observed with the Geissler tube and a bright line of calcium (λ6438.1); six other bright lines of calcium have been identified with metallic lines in the Sun, and the other dark lines with those which I have marked telluric on the plate in Fievez's atlas, and on my unpublished map which I had previously made with the assistance of M. Obrecht.

November 6—Hazy evening; light faint and yellow; water-vapor lines very faint; they were already faint at 2 o'clock that afternoon. No satisfactory observations.

After the close of these evenings of observation I requested the Central Meteorological Bureau to supply me with the data obtained at the top of the tower for the state of the atmosphere from October 28 to November 6.

The variations of temperature and humidity are too slight to be of service in the discussion of the visibility of the spectral lines; the direction and intensity of the wind seem to have exercised more influence.

The following data were transmitted to me:

Date	Temperature	Vapor tension	Wind	
			Direction	Velocity
1899 Oct. 28	11.0	7.1^{mm}	SSW	7.8^{m}
29	9.8	7.4	SSW	10.3
30	10.5	7.3	SSW	12.3
31	7.0	4.9	WNW	1.8
Nov. 1	7.1	6.1	WNW	7.0
2	7.0	5.5	W	9.3
3	9.0	8.6	SW	20.0
4	8.9	7.7	SW	?
5	6.6	5.6	NNE	9.8
6	7.2	5.9	NNE	7.7

In general, the water-vapor lines were sometimes more clearly visible and sometimes less clearly visible than those of the dry atmosphere (bands A, B, *a*); variations in the humidity of the air and the direction of the wind readily explain this effect.

The lines of the dry atmosphere were always less marked than in the solar spectrum: this is due to the short distance (4350 m) traversed by the beam of light as compared with that traversed by the sunlight, even if the Sun were at the zenith. It can easily be shown that the absorbing mass at 4350 m is hardly more than half of that contained in a vertical column of equal base rising vertically to the limits of the atmosphere. The weight of the atmosphere on a square meter is well known to be equal to that of a column of mercury of equal base and 76 cm in height, or $0.76 \times 13596\,\mathrm{kg} = 10333\,\mathrm{kg}$. As a cubic meter of air at the surface of the Earth weighs 1.293 kg, the vertical height of a column of air of uniform density would be $\frac{10333}{1.293} = 7991$ meters.

The horizontal column of 4350 m having the same base thus contains a mass of air smaller in the ratio of 4350 to 7991, or 1 to 0.544, a ratio a little greater than one half. It is therefore not surprising that the lines in the bands A, B, and *a* are relatively less dark than in solar observations when the Sun is near the zenith, and, with even greater reason, when near the horizon.

CONCLUSION.

It follows from the spectroscopic observations given above that more than 200 dark lines, produced by the atmospheric absorption of radiations from a terrestrial source of light, have been identified, one by one, with the so-called *telluric* lines observed in the solar spectrum. The atmospheric origin of these lines is thus verified beyond all question.

OBSERVATIONS OF THE SOLAR ECLIPSE OF MAY 28, 1900.

By H. C. LORD.

IN the July 1900 number of this JOURNAL, Professor Brown gives my preliminary report on the photographs of the flash spectrum secured at Barnesville. In that report the apparatus and method of observing is fully described, but a brief description here may not be out of place. On the eye-end of a four-inch Clark telescope was mounted the large star spectroscope of the Emerson McMillin Observatory. This instrument is provided with two dense 60° prisms. The slit being removed, the image of the solar crescent formed by the four-inch objective acted as the source of light for the spectroscope. The spectroscope and objective were rigidly mounted together and held in a jacket capable of rotation through a small angle about a line perpendicular to the common axis of the four-inch objective and collimator of the spectroscope. The axis of rotation was set at right angles to the line joining the points of second and third contacts, as seen in the six-inch coelostat which reflected the Sun's image into the instrument. The object of this rotation was to shift the instrument during totality, so that the crescents at second and third contacts could be made to fall nearly at the point occupied ordinarily by the slit. In place of an ordinary plate-holder a carriage was provided whereby four exposures could be made on one plate, the plate being shifted the proper amount by simply pressing a rubber bulb. During totality the plate-holder was changed and the carriage set for a second lot of four exposures, and the instrument set as above for third contact. The exposures were made by pulling a string which operated a shutter in front of the four-inch objective. In this way seven photographs were secured, two of which, numbers 3 and 6, were of the flash and will form the subject of this paper.

Plate No. 6 is reproduced, considerably enlarged, in the paper above referred to.

For the measurement of these plates the following plan was adopted. The instrument employed was a Zeiss comparator No. 10. This consists of a stand carrying two micrometer microscopes; under one is placed the plate to be measured and under the other a scale graduated on silver to 1/5 mm. The least reading of the instrument is 0.0001 mm. The scale is 100 mm long, but has only been investigated for division error from 40 to 60. The maximum division error found is 0.0021 mm. In order to confine the measurements to that portion of the scale the plate was measured in two positions. Thus division errors could be applied as far as λ4549.78, above which point the definition of the plate fell off rapidly and the error of pointing on the lines themselves became so large in comparison to any division error found in the part of the scale investigated that it did not seem advisable to use a third position. All lines from D_1 to λ4549.78 are freed from division error.

The two lines at λ5197.56 and λ5188.78 were taken as zero lines. The program of measurement was as follows: Three pointings were made on each of the zero lines; then three pointings on each of the lines to be measured, except where these lines were either wide groups or very hazy, when a single pointing was made (in this case the wave-lengths are carried out only to the nearest Ångström unit); then three more pointings on each of the two zero lines. In this way, not only could the several days' work and the two positions be reduced to a common zero, but any accidental displacement of the plate during a series of measurements could be detected. The zero adopted was the point midway between the two zero lines, and the corresponding micrometer reading was taken as 47.438 mm. Thus the micrometer reading for any other line is given by the equation

$$M = S + m + \Delta + me + 47.438 - \frac{M_1 + M_2}{2},$$

where S is the scale division, m the micrometer reading, Δ the

division error, e the error of runs, and M_1 and M_2 the value of M for each of the zero lines for any day's work, omitting the last two terms of the above formula. The micrometer was read to 0.0001 mm, and after applying me and Δ the ten thousandths were dropped as being meaningless. The means of the three pointings were all made in duplicate. Each plate was measured in duplicate, with an independent estimate of the intensity and character. Table I gives in column 2 the mean intensity of the four estimates on a scale of 20, column 4 the several estimates of the character of the line, column 5 the mean value of M from the two measures of plate 3, and column 8 the corresponding quantity from plate 6.

TABLE I.

Note.—In the column "Character," *S* indicates sharp; *H*, hazy; *B*, broad; *B G*, broad group; $V^2 H$, very, very hazy, and similarly for $V^3 H$; *? H*, doubtful, hazy line; *S B*, sharp band; *B H G*, broad, hazy group; *B P D*, broad, probably double; *W*, wide; *R S V H*, sharp on red side, hazy on violet.

* Normal lines.

Nos. 103 and 157 are very peculiar, being much more intense at the horns than at the vertex of crescent. Vertex too faint to be bisected, set by estimating distance at horns from near companion.

No.	I	Elev.	Character	M Plate 3	Reduced to 6	M Plate 3 Reduced to 6	M Plate 6	Mean	Computed Wave-length	Young's Chrom. Lines		
										λ	F	B
* 1 D_1	4	4½	S-H-HR-H	60.034	−.032	60.002	60.002	60.002	5896.16	5896.16	25	2-10
* 2 D_2	4	4½	S-S-H-S	59.950	−.032	59.918	59.914	59.916	5890.00	5890.18	25	2-10
3 D_3	10	5	S-HR-HR-S	59.780	−.031	59.749	59.746	59.748	5878.05	5876.00	100	90
4	1	1	?H-VH				59.410	59.410	5854.27	5853.90	8	2
5	1	1	Hazy group	57.25	−.02	57.23	57.24	57.24	5710	5709.62	1	1
6	1	1	Hazy group				56.86	56.86	5686	5688.43	2	1
7	1	1	?H-H	56.527	−.023	56.504		56.504	5663.56	5662.75	15	2
8	1	1	Very large & broad ?H				56.478	56.478	5661.96			
9	1	1	S-S-S-S	56.436	−.022	56.414	56.415	56.414	5658.02	5658.10	8	3
10	1	1	S-S	56.160	−.022	56.138		56.138	5641.17	5641.66	1	1
11	1	1	VBH-?H				55.870	55.870	5624.98	5624.77	2	1
12	1	1	H-H-S-S	55.732	−.021	55.710	55.714	55.712	5615.52	5615.88	2	1
13	1	1	HG-HG-HG-H	55.50			55.494	55.494	5602.57			
14	1	1	S-S				55.350	55.350	5594.07			
15	1	1	HPD-BH-HPD-H	55.269	−.020	55.249	55.248	55.248	5588.09	5588.98	2	2
16	1	1	H-H				54.992	54.992	5573.17			
17	1	1	H-H				54.933	54.933	5569.76			
* 18	2	2	S-S-S-S	54.348	−.017	54.331	54.328	54.330	5535.30	5535.07	50	12
19	2	3	S-H-H-B	54.208	−.017	54.191	54.198	54.194	5527.65	5528.64	40	5
20	1	1	H-H-S-S	53.830	−.016	53.814	53.821	53.818	5506.69	5507.0	2	1
21	1	1	H-H-S-H	53.740	−.016	53.724	53.727	53.726	5501.62	5501.69	2	1
22	1	1	H-H-H-S	53.666	−.015	53.651	53.644	53.648	5497.32	5497.73	2	1
23	2	1	S-S-S-S	53.288	−.014	53.274	53.272	53.273	5476.86	5477.13	1	1

TABLE I.—*Continued.*

No.	I	Elev.	Character	M Plate 3	Reduced to 6	M Plate 3 Reduced to 6	M Plate 6	Mean	Computed Wave-length	Young's Chrom. Lines λ	F	B
24	1	1	H-H-S-S	53.024	—.014	53.010	53.010	53.010	5462.70	5463.49	1	1
* 25	3	2½	S-S-S-S	52.894	—.014	52.880	52.883	52.882	5455.86	5455.83	10	4
* 26	2	2½	S-S-S-S	52.731	—.013	52.718	52.716	52.717	5447.08	5447.13	10	4
27	2	2	S-S-S-S	52.496	—.012	52.484	52.481	52.482	5434.69	5434.74	2	2
* 28	2	2	S-S-S-S	52.400	—.012	52.388	52.384	52.386	5429.65	5429.9	8	3
29	1	1	S-S-S-S	52.308	—.012	52.296	52.300	52.298	5425.06	5425.4	25	6
30	1	1	S-S-H-?H	52.198	—.012	52.186	52.183	52.184	5419.12	5419.0	5	2
31	1	1	H-S-H-S	52.116	—.012	52.104	52.106	52.105	5415.03	5415.42	2	2
32	1	1	S-S-S-S	52.020	—.011	52.009	52.006	52.008	5410.02	5410.0	2	2
33	2	2	S-S-S-S	51.936	—.011	51.925	51.927	51.926	5405.79	5405.99	2	1
34	1	1	S-?S				51.896	51.896	5404.25	5404.1	5	3
35	1	2	S-S-S-S	51.772	—.011	51.761	51.761	51.761	5397.34	5397.35	4	2
36	1	1	?H-S				51.686	51.686	5393.51	5393.38	2	1
37	1	1	HG-HG-HG-BG	51.46	—.01	51.45	51.44	51.44	5381	5381.2	3	2
38	3	2½	S-S-S-S	51.262	—.009	51.253	51.250	51.252	5371.58	5371.69	10	3
39	2	2	H-H-V^2H	51.090	—.009	51.081	51.077	51.079	5362.92	5363.01	20	5-10
40	1	1	H-H-S-S	50.906	—.008	50.898	50.887	50.892	5353.65	5353.59	2	2
41	1	1	H-H	50.820	—.008	50.812		50.812	5349.70			
42	1	1	H-S-S-S	50.748	—.008	50.740	50.736	50.738	5346.06	5346.0	1	1
43	1	1	S-S-S-S	50.644	—.008	50.636	50.632	50.634	5340.95	5341.3	2	1
44	1	1	S-S-S-S	50.558	—.007	50.551	50.549	50.550	5336.84	5336.9	5	2
* 45	4	3½	S-S-S-S	50.382	—.007	50.375	50.375	50.375	5328.33	5328.7 28.2	3	2
46	1	1	H-H				50.290	50.290	5324.21	5325.4	2	2
47	4	3½	S-S-S-S	50.146	—.006	50.140	50.135	50.138	5316.88	5316.79	100	2-20
48	1	1	H-??H	49.939	—.006	49.933		49.933	5307.05			
49	1	1	H-H-S-H	49.841	—.006	49.835	49.835	49.835	5302.38			
50	1	1	H-H-B & H-H	49.742	—.005	49.737	49.746	49.742	5297.97			
51	2	1	Note HV-H-H	49.450	—.005	49.445	49.444	49.444	5283.92	5284.2	10	2-6
52	1	1	? H-H				49.390	49.390	5281.39			
* 53	4	3½	S-S-S-S	49.284	—.004	49.280	49.276	49.278	5276.16	5276.21	10	10
* 54	5	3½	S-S-S-S	49.153	—.004	49.149	49.144	49.146	5270.02	5270.50	5	2
55	1	1	Band	49.08	±.00	49.08	49.07	49.08	5267	5266.73	10	4
56	1	1		48.96	±.00	48.96	48.96	48.96	5261	5264.10	1	1
57	1	1	S-S-S-H	48.820	—.003	48.817	48.822	48.820	5254.98	5255.4	1	1
58	1	1	H-S-S-S	48.730	—.003	48.727	48.724	48.726	5250.68	5249.8	3	1
59	1	1	S-S-S-S	48.638	—.002	48.636	48.651	48.644	5246.94	5247.8	2	1
60	2	3	H-SB-S-S	48.364	—.002	48.362	48.374	48.368	5234.42	5234.8	10	10
61	1	1	S-S				48.334	43.334	5232.89	5233.12	1	2
62	1	1	S-S-S-S	48.206	—.001	48.205	48.199	48.202	5226.95	5226.7	5	5
63	3	4	H-H-H-V^2H	47.963	—.001	47.962	47.959	47.960	5216.15	5216.5	3	2
*64	3	4	S-S-H-S	47.796	+.000	47.796	47.788	47.792	5208.70	5208.8 5208.6	4	5
*65	1	1	B-Prob. double	47.723	+.000	47.723	47.714	47.718	5205.43	5205.9	4	5
66	1	1	S-S-S-S	47.540	+.000	47.540	47.538	47.539	5197.56	5197.8	15	10
67	1	1	H-S				47.487	47.487	5195.29	5195.1	2	2
68	1	1	S-S-H-S	47.414	+.001	47.415	47.413	47.414	5192.10			
69	1	1	S-S-S-S	47.337	+.001	47.338	47.338	47.338	5188.78	5189.00	10	5
*70b_1	8	5	S-S-S-S	47.232	+.001	47.233	47.230	47.232	5184.18	5183.79	50	35
*71b_2	5	5	S-S-S-S	46.979	+.002	47.981	46.974	46.978	5173.22	5172.87	50	30
*72b_3	5	4	S-S	47.866	+.002	47.868	46.883	46.865	5169.14	5169.22	40	25
*73b_4	5	4	S-S				46.842		5167.39	5167.57	20	10

TABLE I.—*Continued.*

No.	I	Elev.	Character	M Plate 3	Reduced to 6	M Plate 3 Reduced to 6	M Plate 6	Mean	Computed Wave-length	Young's Chrom. Lines λ	F	B
74	1	1	?H–??H				46.717	46.717	5162.05	5161?	1	1
75	1	1	H–VH–H–H	46.531	+.003	46.534	46.527	46.530	5154.12	5153.5	2	2
76	1	1	? Hazy–V^2 doubtful V–VH	46.456	+.003	46.459	46.459	46.459	5151.12	5151.03	1	1
77	1	1	? H–? H				46.388	46.388	5148.12	5149.2	2	2
78	1	1	H–H–S–H	46.248	+.003	46.251	46.258	46.254	5142.49	5143.04	2	1
79	1	1	S–S–S–H	46.178	+.004	46.182	46.181	46.182	5139.48			
80	1	1	H–? H				46.116	46.116	5136.72			
81	1	1	H–H–S–VH	45.928	+.004	45.932	45.931	45.932	5129.07	5129.8	1	1
82	1	1	H–H	45.789	+.005	45.794		45.794	5123.36	5123.5	2	2
83	1	1	S–S–S–S	45.478	+.005	45.483	45.482	45.482	5110.56	5112.3		
84	1	1	S–S–S	45.398	+.006	45.404	45.408	45.406	5107.46	5107.8	1	1
85	1	1	H–H	45.180			45.24	45.24	5101	5098.8	1	1
86	1	1					45.14	45.14	5097	5097.18	1	1
87	1	1	S–S–S–S	44.902	+.007	44.909	44.912	44.910	5087.43	5087.6	2	1
88	1	1	S–S–H–H	44.798	+.007	44.805	44.807	44.806	5083.28	5084.3	1	1
89	1	1	H–H–H–H	44.706	+.007	44.713	44.716	44.714	5079.61	5079.0	1	2
90	1	1	? H–S–S	44.583	+.008	44.591	44.590	44.590	5074.69			
91	1	1	H–? H–S–H	44.516	+.008	44.524	44.530	44.527	5072.19			
92	1	1	H–H–VH	44.437	+.008	44.445	44.439	44.442	5068.84			
93	1	1	H–H–S–H	44.324	+.008	44.332	44.337	44.334	5064.59			
94	1	1	G				44.21	44.21	5060			
95	1	1	BHG	44.02	+.01	44.03		44.03	5053			
96	1	1		43.89	+.01	43.90		43.90	5048	5048.2	2	2
97	2	1					44.000	44.000	5051.54			
98	2	1	H–H–S–S	43.724	+.010	43.734	43.739	43.736	5041.33	5041.80	2	2
99	1	1	H–H–S–S	43.574	+.010	43.584	43.588	43.586	5035.56			
100	2	1½	S–S–S–H	43.460	+.011	43.471	43.472	43.472	5031.20	5031.3	4	3
101	1	1	S–S				43.376	43.376	5027.54			
*102	5	4½	S–S–S–S	43.132	+.012	43.144	43.139	43.142	5018.67	5018.6	30	15
103	2	4½	Note	43.064	+.012	43.076	43.056	43.066	5015.80	5015.9	30	10
104	1	1	? H–V^3H				43.034	43.034	5014.59			
105	1	1	S–S	42.987	+.012	42.999		42.999	5013.28			
106	1	1	S–S–H–S	42.943	+.012	42.955	42.968	42.962	5011.89			
107	1	1	BH–BH–HG–BG	42.796	+.012	42.808	42.81	42.808	5006.12			
108	1	1	BHG–BHG	42.64			42.71	42.71	5002			
109	1	1					42.61	42.61	4999			
110	1	1	H–VH–S–S	42.462	+.013	42.475	42.477	42.476	4993.78	4994.32	2	1
111	1	1	S–VH–S–H	42.378	+.013	42.391	42.400	42.396	4990.83			
112	1	1	Hazy group	42.15	+.01	42.16	42.18	42.17	4982			
*113	3	3½	S–S–S–S	41.466	+.16	41.482	41.480	41.481	4957.57	4957.48	1	2
114	1	1	Hazy				41.165	41.165	4946.31			
115	1	1	H–H–VH–H	40.937	+.017	40.954	40.958	40.956	4938.92			
*116	5	4	S–S–S–S	40.806	+.017	40.823	40.820	40.822	4934.21	4934.02	30	5
*117	5	4	S–S–S–S	40.514	+.018	40.532	40.534	40.533	4924.12	4924.11	40	10
118	1	1	S–S with shading				40.432	40.432	4920.61	4919.18	20	5
119	1	4	Note				40.390	40.390	4919.16	4919.1	20	3
120	1	1	S–H				40.238	40.238	4913.91	4912.3	3	2
121	1	1	HB–BG	40.12	+.019	40.14	40.140	40.140	4910.54			
122	1	1	V^2H–V^2H–S–S	39.921	+.020	39.941	39.920	39.930	4903.35			
123	1	1	S–S				39.960	39.960	4904.37			
*124	2	1½	S–S–S–S	39.814	+.020	39.834	39.832	39.833	4900.05	4900.31	30	6

TABLE I.—*Continued.*

No.	I	Elev.	Character	M Plate 3	Reduced to 6	M Plate 3 Reduced to 6	M Plate 6	Mean	Computed Wave-length	Young's Chrom. Lines λ	F	B
125	2	2	S-S-H-S	39.552	+.020	39.572	39.574	39.573	4891.24			
*126	2	2	S-S-H-H	39.328	+.021	39.348	39.351	39.350	4883.74	4883.94	10	4
127	1	1	HG-H-S-S	39.142	+.021	39.163	39.190	39.176	4877.92			
128	2	1	SB-H-H-H	38.968	+.022	38.988	38.989	38.988	4871.67	4870.4	5	1
129 F	20	5	S-S-VBS-S	38.668	+.023	38.691	38.669	38.680	4861.51	4861.50	100	80
130	1	1	G on 3-S-S	38.45	+.02	38.47	38.488	38.488	4855.22	4855.5	5	2
131	1	1	S-H-BH-V^2H	38.255	+.024	38.279	38.276	38.278	4848.39	4848.7	3	2
*132	2	3½	S-BPD-BH-H	37.489	+.026	37.515	37.517	37.516	4823.95	4824.33	10	2
133	1	1	H-H				37.102	37.102	4810.90			
*134	2	3½	H-B-S-S	36.891	+.027	36.918	36.918	36.918	4805.16	4805.25	3	1
135	1	1	S-S				36.712	36.712	4798.76			
136	1	1	S-S				36.412	36.412	4789.51			
137	1	1	S-S				36.316	36.316	4786.52			
138	1	1	H-H-S-S	36.184	+.029	36.213	36.216	36.214	4783.45			
139	1	1	H-H-S-S	36.078	+.029	36.107	36.102	36.104	4780.10	4779.7	3	2
140	1	1	S-?S				35.969	35.969	4776.00			
141	1	1	Wide group				35.86	35.86	4773			
142	1	1	H-H				35.646	35.646	4766.26			
143	2	1	BG-HWG	35.52			35.60	35.60	4765			
144							35.49	35.49	4762			
145	1	1	S-V^3H-H-H	35.206	+.032	35.238	35.236	35.237	4754.06			
146	1	1	S-H				34.952	34.952	4745.64			
147	1	1	W-H				34.651	34.651	4736.82			
148	1	1	H-H-S-S	34.434	+.034	34.468	34.477	34.472	4731.62	4731.7	1	1
149	1	1	?H-H				34.342	34.342	4727.85			
150	1	1	VH-V^2H				34.147	34.147	4722.23			
151	4	5	S-S-HW-SSR	33.820	+.036	33.856	33.840	33.848	4713.67	4713.4	2	2
152	1	1	Wide group	33.62	+.04	33.66	33.73	33.73	4710			
153	1	1					33.60	33.60	4707			
154	1	1	H-H-S-S	33.442	+.036	33.478	33.472	33.475	4703.09			
155	1	1	VH—H				33.338	33.338	4699.23			
156	1	1	S-H				33.064	33.064	4691.56			
157	1	4½	Note	32.840	+.038	32.878	32.870	32.874	4686.28			
158	1	1	S-H-S-S	32.694	+.038	32.732	32.725	32.728	4682.24			
159	2	1	H-H-S-S	32.260	+.039	32.299	32.306	32.302	4670.54			
160	2	1	H-H-H-H	32.134	+.039	32.173	32.180	32.176	4667.10	4667.5	3	1
161	1		Broad group				32.02	32.02	4663	4664.2	2	1
162	1	1	H-S-H-VH	31.768	+.040	31.808	31.804	31.806	4657.09	4657.1	2	1
163	1	1	H-V^2H				31.712	31.712	4654.56			
164	2	1	H-H-S-BH	31.575	+.041	31.616	31.610	31.613	4651.90			
165	2	1	H-S•R-S^2R-V^2H	31.359	+.042	31.401	31.404	31.402	4646.27			
166	1	1	?H-?H				31.074	31.074	4637.57			
167	1	1	H-V^2H-S-H	30.910	+.043	30.953	30.948	30.950	4634.30			
*168	4	3	S-S-S-S	30.722	+.043	30.765	30.767	30.766	4629.47	4629.52	15	18
169	1	1	H-V^2H				30.652	30.652	4626.49			
170	1	1	S-H				30.438	30.438	4620.92	4621.1	1	1
171	1	1	H-S^2R-H-H	30.318	+.044	30.362	30.370	30.366	4619.05			
172	1	1	H-H-BH-BVH	30.219	+.045	30.264	30.258	30.261	4616.34			
173	1	1	BH-V^2H				30.152	30.152	4613.53			
174	1	1	H-??V^2H				30.068	30.068	4611.37			
175	1	1	H-VH				29.736	29.736	4602.88			
176	1	1	H-H-BH-BH	29.608	+.046	29.654	29.644	29.649	4600.67			

TABLE I.—*Continued.*

No.	I	Elev.	Character	M Plate 3	Reduced to 6	M Plate 3 Reduced to 6	M Plate 6	Mean	Computed Wave-length	Young's Chrom. Lines λ	F	B
177	1	2	H–H–S–S	29.192	+.047	29.239	29.230	29.234	4590.18	4590.13	1	1
178	1	1	H–H–S–H	29.116	+.047	29.163	29.160	29.162	4588.37	4588.38	2	2
179	4	4	RSVH–S–S–S	25.940	+.048	28.988	28.982	28.985	4583.94	4584.1	15	6
180	1	1	S–H				28.836	28.836	4580.23			
181	1	1	S–S–H–H	28.634	+.048	28.682	28.686	28.684	4576.46	4576.6	4	2
*182	5	4½	S–S–S–S	28.464	+.049	28.513	28.505	28.509	4572.14	4572.16	10	4
*183	4	4½	S–S–S–S	28.130	+.050	28.180	28.174	28.176	4563.96	4563.94	10	5
184	1	3	S–S–S–H	27.918	+.050	27.968	27.962	27.965	4558.82	4558.9	8	1
185	1	1	S–S	27.805	+.051	27.856		27.856	4556.18	4556.2	10	5
186	5	4½	S–S–S–S	27.726	+.051	27.777	27.771	27.774	4554.19	4554.21	10	5
*187	5	4½	S–S–S–S	27.541	+.051	27.592	27.590	27.591	4549.78	4549.8	10	8
188		1	Broad Group				27.44	27.44	4546			
189							27.34	27.34	4544			
190		1	Broad Group				27.26	27.26	4542			
191							indefinite			4540	2	1
*192	5	4½	S–S–S–S	26.887	+.053	26.940	26.932	26.936	4534.15	4534.2	5	5
193	1	1	VH–V^{2}H				26.806	26.806	4531.08			
194	1	1	H–V^{2}H				26.712	26.712	4528.86			
195	2	2½	S–S–S–H	26.400	+.054	26.454	26.452	26.453	4522.79	4522.9	3	3
196	1	1	H–H–H–VH	26.286	+.054	26.340	26.348	26.344	4520.25			
197	2	1½	H–H–H–V^{2}H	26.080	+.055	26.135	26.136	26.136	4515.41	4514.5	2	1
198	2	1½	H–H–H–V^{2}H	25.777	+.056	25.833	25.831	25.832	4508.39	4506.9	2	1
*199	5	4½	S–S–S–H	25.472	+.057	25.529	25.525	25.527	4501.40	4501.44	15	6
200	1	1	BH–V^{2}H				25.336	25.336	4497.05			
201	1	1	H–V^{3}H				25.217	25.217	4494.35			
202	1	1	H–V^{3}H				25.082	25.082	4491.30	4491.5	20	8
203	1	1	Broad Group	25.06	+.06	25.12		25.12	4492			
204	1	1		24.88	+.06	24.94		24.94	4488			
205	1	1	BH–V^{2}H				24.993	24.993	4489.29	4490.2	15	3
206	1	1	V^{2}H–G–BH–V^{2}H	24.608	+.059	24.667	24.674	24.670	4482.05	4481.7	5	2
207	1	1	H–V^{2}H				24.396	24.396	4475.95			
208	10	5	S–S–H–H	24.160	+.060	24.220	24.200	24.210	4471.83	4471.8	100	25
209	5	4½	S–S–H–H	24.006	+.060	24.066	24.060	24.063	4468.59	4469.5	20	5
210	1	1	S–V^{2}H				23.878	23.878	4464.53			
211	1	1	V^{2}H–V^{2}HG–H–V^{2}H	23.682	+.060	23.743	23.736	23.740	4461.51			
212	1	2	V^{2}H–H–VH–V^{2}H	23.369	+.062	23.431	23.428	23.430	4454.77			
213	1	2	V^{2}H–V^{3}H–VH–V^{2}H	23.165	+.062	23.227	23.238	23.234	4450.54			
214	5	4½	H–VH–H–VH	22.862	+.063	22.925	22.924	22.924	4443.88	4443.5	10	2
215	1	1	BH–V^{2}H–VH–V^{2}H	22.450	+.064	22.514	22.515	22.514	4435.15	4434.0	1	1
216	1	1	V^{2}H–VH–VH–V^{2}H	22.074	+.065	22.139	22.138	22.138	5427.22	4426.6	2	3
217	1	1	V^{2}H–V^{2}H–G	21.834	+.066	21.900	21.90	21.900	4422.24			
218	4	2½	V^{2}H–V^{2}H–VH–V^{3}H	21.617	+.066	21.683	21.678	21.680	4417.66	4419.0	2	1
219	3	2½	V^{2}H–V^{2}H–VH–V^{3}H	21.488	+.067	21.555	21.554	21.554	4415.05	4415.30	1	1
220			Hazy Group				21.22	21.22	4408	4408.6	1	1
221	1	1	V^{2}H–V^{2}H	21.146	+.068	21.214		21.214	4408.04	4408.6	1	1
222	2	3½	V^{2}H–V^{2}H–VH–V^{3}H	20.975	+.068	21.041	21.052	21.046	4404.60	4404.93	1	1
223	3	3½	V^{3}H–V^{3}H–VH–V^{3}H	20.737	+.069	20.806	20.822	20.814	4399.87	4398.9	1	1
224	5	4½	V^{2}H–V^{2}H–VH–V^{2}H	20.495	+.069	20.564	20.574	20.569	4394.90	4395.2	15	3
225	3	3½	V^{2}H–V^{2}H–VH–V^{3}H	19.924	+.071	19.995	20.003	19.999	4383.46	4383.72	1	1
226	3	3½	V^{3}H–V^{2}H–V^{2}H–V^{3}H	19.480	+.072	19.552	19.562	19.557	4374.69	4374.8	8	3
227	1	1	V^{2}H–V^{4}H				18.74	18.74	4359	4359.78	1	1
228	2	1	V^{2}H–V^{4}H				18.36	18.36	4351	4352.4	3	1
229*Hγ*	15	5	VBSH–V^{5}H				17.79	17.79	4340	4340.66	100	65

These plates were taken so nearly at the instant of contacts that the continuous spectrum is reduced to a few narrow streaks, which when examined under a low power are seen to be full of bright lines, and when examined under the measuring engine lose all appearance of a continuous spectrum and appear simply as streaks of maximum density of the bright lines. They supply, however, an easy means of adjusting the plate parallel to the scale, it being only necessary to make a spot of dust in the eyepiece follow the streak as the plate is moved rapidly from end to end. As the instrument at Barnesville was set for the mean position angle of the two contacts, the tangents to the solar crescents at the points where crossed by the streaks are not at right angles to the direction of the streaks, and it would be very difficult to make an accurate pointing were the micrometer wire set perpendicular to the direction of motion of the plate under the microscope. This difficulty was entirely avoided by rotating the plate micrometer until its wire was tangent to the curved lines where crossed by the streak, keeping the plate micrometer constantly at zero and making the bisections with the slow motion that moved simultaneously both plate and scale. With this precaution I think nearly if not quite as accurate pointings can be made as if the lines were straight.

In comparing the values of M from plate 3 and plate 6 as given in Table I, it is at once evident that there is a progressive difference in the value $M_3 - M_6$. This can be due to two causes: first, in shifting the instrument at Barnesville during totality from its setting for second contact to that for third it was impossible to bring the image of the solar crescent to exactly the same point in the focal plane of the collimator. This would produce an effect exactly similar to a slight shift of the slit of the spectroscope parallel to itself, and would result in the lines on the two plates having a progressive shift. Secondly, should the long lines be at a greater elevation above the Sun's limb than the short ones, these would be shifted relatively to the short ones, too far to the violet on one plate and too far to the red on the other. In order to test if there were any such relative displacement as

this latter would indicate, 72 short lines common to both plates 3 and 6 were selected and the residuals $M_3 - M_6$ plotted on cross section paper. It was at once seen that these residuals could be represented about as well by a straight line as by any other form of curve; accordingly a straight line was passed through them by the method of least squares and the equation

$$M_6 = M_3 + 0.0016 \text{ mm} - 0.00256 \text{ mm } (M - 47.0)$$

was found. The values of these corrections are given in Table I, column 6; column 7 gives the value of M for plate 3 thus reduced, and column 9 the mean value of M from plates 6 and 3 thus reduced. Since this correction was based solely upon the short lines, it is evident that, were the long lines at any considerable elevation, this would show in the difference $M_3 - M_6$ after M_3 had been reduced to plate 6 as above. Table II gives this difference for all lines having a length greater than 4.

Assuming that the differences in column $M_3 - M_6$ correspond to a difference of elevation of the substance emitting the given line, and that the stratum was of uniform brilliancy, it is evident that the elevation of its upper limit would be given by the expression.

$$E = 206264 \times 450 \times \frac{f_1 \,(M_6 - M_3)}{1000\, f_2 \times F} = 64\ (M_6 - M_3)$$

where E = elevation in miles, $f_1 = 383$ mm = focal length of collimator, $f = 375$ mm = focal length of camera, $F = 1486$ mm = focal length of image lens, and $M_6 - M_3$ is expressed in 0.001 mm. This, of course, would be exact only for minimum deviation, but would be sufficiently accurate for the extent of spectrum covered by these plates. Upon this assumption I have computed the elevations given in Table II.

Of the two negative values found, one is so small as to be easily accounted for by accidental errors of observation, while for the third the line is near the limit of the plate and is so badly out of focus as to render the measurements very uncertain. The four lines whose elevation comes out greater than 1000 miles are F, 4713.67, 4471.83, and 5015.80. The behavior of this latter line

TABLE II.

No.	λ	M_e	M_s	M_s-M_e	E in miles
1 D_1	5896.16	60.002	60.002	±0.000	±0
2 D_2	5890.00	54.914	59.918	+0.004	+256
3 D_3	5878.05	59.746	59.749	+0.003	+192
45	5328.33	50.375	50.375	±0.000	±0
47	5316.88	50.135	50.540	+0.005	+320
53	5276.16	49.276	49.280	+0.004	+256
54	5270.02	49.144	49.149	+0.005	+320
62	5226.95	48.199	48.205	+0.006	+384
64	5208.70	47.788	47.796	+0.008	+512
65	5205.43	47.714	47.723	+0.009	+576
70	5184.18	47.230	47.233	+0.003	+192
71	5173.22	46.974	46.981	+0.007	+448
½ (72+73)	½ (63+64)	46.862	46.868	+0.006	+384
102	5018.67	43.139	43.144	+0.005	+320
103	5015.80	43.056	43.076	+0.020	+1280
113	4957.57	41.480	41.482	+0.002	+128
116	4934.21	40.820	40.823	+0.003	+192
117	4924.12	40.534	40.532	−0.002	−128
129 F	4861.51	38.669	38.691	+0.022	+1408
132	4823.95	37.517	37.515	+0.002	+128
134	4805.16	36.918	36.918	±0.000	±0
151	4713.67	33.840	33.856	+0.016	+1024
157	4686.28	32.870	32.876	+0.008	+512
179	4583.94	28.982	28.988	+0.066	+384
182	4572.14	28.505	28.513	+0.008	+512
183	4563.96	28.174	28.180	+0.006	+384
186	4554.19	27.771	27.777	+0.006	+384
187	4549.78	27.590	27.592	+0.002	+128
192	4534.15	26.932	26.940	+0.008	+512
199	4501.40	25.555	25.529	+0.004	+256
208	4471.83	24.200	24.220	+0.020	+1280
209	4468.59	24.060	24.066	+0.006	+384
214	4443.88	22.924	22.925	+0.001	+64
224	4394.90	20.574	20.564	−0.010	−640

is, however, very peculiar, and is similar to that of the line at 4686.28. Both these lines on both plates show much more markedly at the horns of the crescent than at the vertex, where they seem to almost entirely disappear, so much so in fact that it was impossible to actually set the micrometer wire upon them at the vertex, and the measurements were made by estimating the distance at the horns from a close companion. This peculiarity is shared by no other lines found on either plate, and is clearly marked for both lines on each plate. I feel, therefore, that these two lines must be common to some substance, and

that they are not due to a substance which shows other lines on the photographs.

Since the above was written Professor Frost has called my attention to the close agreement of three of these lines with those found by Runge and Paschen[1] in the spectrum of Clèveite gas. The line 4713.67, with an intensity of 1, agrees with the mean of the two lines 4713.252, intensity 3, and 4713.475, intensity <1, within the limit of error of my wave-lengths; 4471.83, intensity 10, agrees with the mean of 4471.646 and 4471.858, intensities 6 and <1 respectively, and 5015.80, intensity 2, with 5015.732, intensity 6. The first two belong to the second and first subordinate series of helium proper, the last to the principal series of the lighter constituent. This explanation would be very satisfactory were it not for the line at 4686.28, which is not found by these observers in Clèveite gas, nor by Kayser in the spectrum of argon. Rowland gives a line at 4686.40 with an intensity 3 as due to *Ni*, but this line in its behavior is so exactly like that at 5015.80, and so radically different from all the others, that I cannot believe it can be due to *Ni*. In a paper entitled "The new Series in the Spectrum of Hydrogen,"[2] Rydberg deduces from his formulæ on page 236 a line at 4687.88, concerning which he says:

> These conclusions are confirmed in every respect, if we consider the spectra of stars of the fifth type. . . . . As we see, *all the known lines of hydrogen are surpassed in intensity by the line 4688, which corresponds almost exactly to the computed value 4687.88 and which we can, with full certainty, indicate as the first line of the hydrogen spectrum, being at once the first term of the principal and of the sharp series.*

The line 4686.28 may well be this hydrogen line; the difference in wave-length, 1.6 Ångström units, is somewhat large, but the peculiar character of the line made measurements rather uncertain. Its intensity is, however, much less than that of the other hydrogen lines, being certainly not over $\frac{1}{10}$ that of either $H\beta$ or $H\gamma$.

The low value of these elevations appears to me somewhat surprising. Even if the stratum which gives rise to these radiations

[1] Astrophysical Journal, 13, 4, 1896. [2] Astrophysical Journal, 6, 233.

at greater elevation is not of uniform intensity, but much brighter on the inner side, it would hardly seem that the center of density should come very much nearer the level of the shorter crescents. And in that case the crescent should appear sharp on the inner edge and hazy on the outer, a condition of affairs which is by no means markedly in evidence. Furthermore, the elevations are in a great many cases but a very small fraction of the width of the line, thus indicating that the high level (long) lines, while being shifted bodily by a small amount relatively to the low level (short) lines, have nevertheless been broadened on each side of this shifted position by a much greater amount. If this be true, the explanation is not at once apparent, at least to me. That the shift above is real, and an approximation at least to the true amount, is confirmed by plate 1, exposed several seconds before totality. Here both the dark and bright F lines are seen side by side, evidently overlapping but not superimposed. A number of other lines are found both bright and dark, but only in the case of F was the definition good enough to permit even an approximation to a measurement. The value found in this case was 0.033mm, or 2112 miles, as the distance between the centers of 4224 from the outer edge of the high level stratum. But these lines clearly overlapped, as both the bright and dark F lines narrowed down where they came together, thus tending to greatly increase the measured elevation. I have given this discussion thus fully, for I can see no instrumental cause that would cause this shift, and am at a loss to understand why it is not greater in amount. I can only say that I have given the facts as they have been observed, absolutely without bias, as I was ignorant until all the computations had been finished as to whether this shift corresponded to a low or high elevation.

DETERMINATION OF WAVE-LENGTHS.

For the determination of the wave-lengths the following plan was adopted. Three normal places were formed from the measurements given in column 9, Table I. For the first normal place D_1, D_2, and D_3, were used; for the second, b_1, b_2, and $\frac{b_3+b_4}{2}$;

for the third, F. From these the following normal places were found:

$$
\begin{aligned}
\text{For}\quad M &= 59{,}900 \quad \lambda = 5888.35 \\
M &= 47{,}000 \quad \lambda = 5173.95 \\
M &= 38{,}680 \quad \lambda = 4861.50
\end{aligned}
$$

From these a Cornu-Hartmann interpolation formula was computed, giving the following equation:

$$\lambda = 2697.89 - \frac{[5.1542630n]}{M - 104{,}610}\ .$$

With this formula the normal lines given in Table III were identified with lines in Young's list of chromospheric lines as revised by Frost in his *Astronomical Spectroscopy*. The first column gives the number, the second the intensity, the third the adopted value of λ, the sixth the value of M computed by the above formula, the seventh the observed value of M, being the mean of plate 6 and plate 3 reduced as above to plate 6, the eighth C—O; the ninth, tenth, and eleventh columns are from Young's list of chromospheric lines. The remaining columns explain themselves.

I think this table explains the values of the adopted wave-lengths. In adopting these values, while adhering to no fixed rule, but trusting to my judgment as to what seemed the probable value from the material at my command, I was guided by the following considerations: Where two lines were found too close to be resolved on my plates, and of equal or nearly equal intensity as given by Kayser and Runge in the arc spectrum, their mean wave-length was adopted, while if their intensities were markedly different, that of the brighter one was used. In every case Rowland's value of λ was employed. Though these adopted wave-lengths may be slightly in error, I do not believe they will be so changed as to appreciably alter the wave-lengths computed from them as normal lines, even though they may change quite appreciably the constants of the interpolation formula. D_3 and F were rejected from this second list of normal lines as being by far too wide for accurate measurement. From these 28 residuals, corrections to λ_0, c, and

TABLE III.

Number	I	Adopted λ	Computed λ	C—O	Computed M	Observed M	C—O	Young's Chrom. lines λ	F	B
1 D_1	4	5896.16	5896.16	±0.00	60.009	60.002	+0.007		50	30
2 D_2	4	5890.19	5890.00	−0.19	59.925	59.916	+0.009		50	30
18	2	5535.35	5535.30	−0.05	54.337	54.330	+0.007	5535.07	50	12
25	3	5455.83	5455.86	+0.03	52.888	52.882	+0.006	5455.83	10	4
26	2	5447.13	5447.03	−0.05	52.724	52.717	+0.007	5447.13	10	4
28	2	5429.91	5429.65	−0.26	52.397	52.386	+0.011	5429.9	8	3
45	4	5328.47	5328.33	−0.14	50.383	50.375	+0.008	{ 5328.7 5328.2	3 3	2 2
53	4	5276.21	5276.16	−0.05	49.284	49.278	+0.006	5276.21	10	10
54	5	5270.14	5270.02	−0.12	49.154	49.146	+0.008	{ 5270.5 5269.72	5 10	2 2
64	3	5208.69	5208.70	+0.01	47.797	47.792	+0.005	{ 5208.8 5208.6	4	5
65	1	5205.50	5205.43	−0.07	47.724	47.714	+0.008	5205.9	4	5
70 b_1	8	5183.79	5184.18	+0.39	47.228	47.232	−0.004		50	35
71 b_2	5	5172.86	5173.22	+0.34	46.974	46.978	−0.004		50	30
$\frac{72+73}{2}\ \frac{1}{2}(b_3+b_4)$	5	5168.36	5168.37	+0.01	46.869	46.865	+0.004		40 20	25 10
102	5	5018.63	5018.67	+0.04	43.144	43.142	+0.002	5018.5	30	15
113	3	4959.63	4957.57	−0.06	41.485	41.481	+0.004	4957.48	2	1
116	5	4934.24	4934.21	−0.03	40.824	40.822	+0.002	4934.2	30	5
117	5	4924.11	4924.12	+0.01	40.534	40.533	+0.001	4924.11	40	10
124	2	4900.10	4900.05	−0.05	39.335	39.833	+0.002	4900.31	30	6
126	2	4883.87	4883.74	−0.13	39.855	39.350	+0.005	4883.9	10	4
132	2	4824.01	4823.95	−0.06	37.517	37.516	+0.001	4824.33	10	2
134	2	4805.28	4805.16	−0.12	36.921	36.918	+0.003	4805.25	3	1
168	4	4629.52	4629.47	−0.05	30.762	30.766	−0.004	4629.52	15	18
182	5	4572.16	4572.14	−0.02	28.502	28.509	−0.007	4572.16	10	4
183	4	4563.94	4563.96	+0.02	28.167	28.176	−0.009	4563.94	10	5
187	5	4549.72	4549.78	+0.06	27.579	27.591	−0.012	4549.8	10	8
192	5	4534.14	4534.15	+0.01	26.926	26.936	−0.010	4534.2	5	5
199	5	4501.44	4501.40	−0.04	25.518	25.527	−0.009	4501.44	15	6

M of the interpolation formula, together with their weights and probable errors, were computed by the method of least squares, and the final values found were

$$\lambda = (2695.60 \pm 0.64) - \frac{(142857 \pm 79)}{M - (104.637 \pm 0.018)} ,$$

while the probable error of an observation of M, whose weight is unity, came out $\pm$ 0.0022 mm, corresponding to a probable error of λ at $m = 20$, of $\pm$ 0.04 ; at $m = 40$, of $\pm$ 0.07; and at $m = 60$, of $\pm$ 0.16.

TABLE III.

Rowland's intense lines									Kayser and Runge's Fe_2 lines						Hasselberg's *Ti* lines					
λ	I	Ele.	λ	I	Ele.	γ	I	Ele.	λ	I	λ	I	λ	I	λ	I	λ	I	λ	I
6.16																				
0.19																				
5.06	2	*Fe*	5.64	2	*Fe*				5.52	4	4.86	6								
5.83	4	*Fe*	5.67	2	*Fe?*				7.72	5	5.80	1	4.53	6						
6.80	2	*Ti*	7.13	*Fe*	*6d?*				7.05	1					6.80	2				
9.91	*6d?*	*Fe*							9.81	1	9.11	6			9.37	2.3				
8.24	8	*Fe*	8.70	2	*Fe*				8.15	1	8.50	2	8.94	6						
5.93	1	*Cr*	6.17	3	*Fe?*	6.24	2	*Cr*	6.19	6										
9.72	8	*Fe*	0.56	4	*Fe*				9.65	1	0.43	1								
8.60	5	*Cr*	8.78	2	*Fe*															
4.77	3	*Fe*	4.68	5	*Cr*	6.22	5	*Cr, Ti*												
3.79																				
2.86																				
8.36																				
8.63	4	*Fe*	8.46	1	*Ni*				8.53	4					8.50	2				
7.48	5	*Fe*	7.78	8	*Fe*				7.80	2	7.43	3								
4.21	3	*Ba*	4.28	4	*Ba*															
4.11	5	*Fe*	4.96	3					4.00	6	4.89	5								
0.10	2	*Ti, Ca*	0.30	2	*Yi*										0.08	3				
3.87	2	*Yt*																		
3.70	5	*Mn*	4.32	3	*Fe*				3.63	4	4.27	6								
5.28	3		5.61		*O, Ti*										5.25	1.2	5.56	2.3		
9.52	6	*Ti, Co*																		
2.16	6	*Ti*													2.15	3				
3.94	4	*Ti*													3.60	1.2	3.94	2.3		
9.64	2	*Fe*	9.81	6	*Ti, Co*															
4.14	6	*Ti, Co*																		
1.44	5	*Ti*																		

With this equation the wave-lengths of the normal lines were computed and are given in column 4, Table III, and the residuals C − O in column 5. The average probable error of a single wave-length deduced from these residuals comes out ± 0.09.

With this equation the final wave-lengths given in Table I were computed. These were first computed directly with seven-place logarithms and checked by computing a table for every millimeter of *M* from 20 to 60 and interpolating, using second differences; they are, I think, free from any errors of computation.

I have carried these wave-lengths out to the $\frac{1}{100}$ of an Ångström unit, not because I think the hundredths are of real significance, but, except in the case of very broad lines, such as D_1, F, and $H\gamma$, and in cases of lines classed as very hazy, I believe the tenths are, and it was as easy to carry out the computation to the $\frac{1}{100}$ as to be certain of having the tenths correct. The normal lines were not extended beyond λ4549.78, as above this point the want of definition due to the non-achromatic properties of the instrument employed became very marked. But I computed their wave-lengths, as one does not feel inclined to throw away any material secured at the time of an eclipse, even if not of very great value.

I had hoped to be able to determine the elevations of these lines by measuring the arc of their crescents. But it soon became evident that measurements of this character would be valueless, since the irregularities of the Moon's surface were so large in proportion to the elevations that lines frequently appeared, disappeared, and reappeared again several times. I decided therefore to divide the lines into five classes and denote their elevations on a scale of from 1 to 5, 1 being the shortest and 5 the longest.

To Table I, I have added three columns, giving all lines in Young's list of chromospheric lines which are certainly found on my plates and in addition those lines of Young's list which, though near the lines of my plate, yet seem so far away as to render the identification doubtful. The remaining 86 lines are certainly not present in Young's list, while a number of the lines given in Young's list are not found on my plates.

It was my original intention to make no effort at identifications of these lines, but at Professor Frost's suggestion I have made a careful comparison with the Fraunhofer lines given by Rowland in his table of solar spectrum wave-lengths and the results are so striking that I think they would be of general interest. In comparing spectra obtained with two instruments differing greatly in resolving power, great caution must be observed in order to avoid faulty identifications. It is evident that a group

of two or more lines shown by Rowland as widely separated and differing considerably in their relative intensities might all merge into one in my instrument; and the question to be answered is, at what point of the resulting superimposed diffraction patterns will the point of maximum density occur. The case of two lines of equal intensity is simple enough, but if the intensities differ widely we may find the point of maximum density anywhere between the mean of the two and the center of the strongest line. What seemed to me, therefore, a plausible plan to follow was to select all the lines of Rowland's list, having an intensity of 1 or greater, which may fairly be considered as possibly combining into one on my plates. In order to determine the point of maximum density of this group of lines I multiplied the wave-length of each by its intensity, added their products together, and divided the sum thus formed by the sum of the intensities. By this somewhat arbitrary method I have made my comparison and find that of the 200 lines given in my table, whose wave-lengths are carried out to $\frac{1}{100}$ of an Ångström unit, 163 or 81 per cent. have residuals of between 0 and 0.3 of an Ångström unit, 20 or 10 per cent. residuals of from 0.3 to 0.4, 6 or 3 per cent. of from 0.4 to 0.5, 6 or 3 per cent. of from 0.5 to 0.71 and 5 or $2\frac{1}{2}$ per cent. have no corresponding line in Rowland's list; of these, one is D_3, and three others have been shown to agree with lines in the spectrum of Clèveite gas. The remaining one at λ 5661.96 is found on only one of my plates and was classed as "very large and broad" the first time and "doubtful and hazy" the second; its intensity is estimated as 1. If we regard the intensity of such a group of lines as equal to the sum of the intensities of its components the agreement of my estimated intensities with those computed from Rowland's table is far from satisfactory, the relative intensities being frequently reversed. The character of the lines, however, agrees better. In most cases a line classed as broad or hazy corresponds to a group of several lines, though this is not always so. In view of the above facts I feel safe in saying that so far as these two plates are concerned the lines may be completely explained by

a reversal of *some* of the Fraunhofer lines combined with a change in their relative intensities, plus those lines due to helium.

That the flash spectrum is the reversal of all the Fraunhofer lines is far from being borne out by my plates. Of the 1144 solar lines given by Rowland within the limits of my plates and having an intensity of 1 or over, a total of only 445, or 40 per cent., can by any fair assumption be considered as making up lines or groups on my plates, and among the 60 per cent. lacking are many of the brightest lines. Thus there are 73 lines with an intensity of 4 or greater certainly not found on my plates, over one half of which are due to iron. Why this should be so is not easy to see; possibly they are at such low levels as not to have been caught on my plates, in which case iron must give a different spectrum at high levels than at low. However, whatever may be the explanation, I simply offer the facts as they have been observed.

In conclusion I wish to express my deep obligation to Professor Brown and the other members of the Naval Observatory staff at Barnesville, whose cordial support and earnest coöperation made this work possible. It is also proper to state that the actual expense of this work was borne by the government, while the trustees of the Ohio State University granted me a month's leave of absence.

EMERSON MCMILLIN OBSERVATORY,
OHIO STATE UNIVERSITY,
December 10, 1900.

Minor Contributions and Notes

COÖPERATION IN OBSERVING VARIABLE STARS.[1]

The number of known variable stars of long period is now so great, and is increasing so rapidly, that the observation of many of them has been greatly neglected. Observations by Argelander's method are so easily made that they are especially adapted to observers who, for various reasons, cannot use precise photometric methods. In the case of variables of small range, including those of short period and many of the *Algol* variables, the subjective errors greatly diminish the value of observations by Argelander's method. In these cases, also, the periods and light curves appear to be so regular that continuous observations are not needed. It appears to be better to observe such objects photometrically throughout their variation, if possible, and thus determine the light curves. Small variations in the period can then be determined by occasional observations at times when the light is varying most rapidly. Many of the variables of long period appear to change irregularly, and continuous observations are required until the nature of the changes are known. Moreover, the range is, in many cases, so great that the errors of observation are not sufficient to affect seriously the form of the curve. The method of observation for these stars, which has been in use here for the last twelve years, is as follows: A sequence of comparison stars is first selected as near the variable as possible, and each about half a magnitude brighter than the next in order, the brightest being somewhat brighter than the variable at maximum, and the faintest fainter than the variable at minimum. Care is taken not to include double stars or those near brighter stars. The stars brighter than the tenth magnitude are then measured with the meridian photometer. This has been done for nearly all of the comparison stars selected here. Magnitudes determined with the meridian photometer, for all stars of the seventh magnitude and brighter, can now be furnished upon a uniform system. For the fainter stars, measures have been made of large numbers of stars as

[1] *Harvard College Observatory Circular* No. 53.

faint as the thirteenth magnitude, and photometers are now in use with which the faintest stars visible in the largest telescopes can be measured. As the apparent magnitude may sometimes differ from the measured magnitude, it has been found best to estimate independently on several nights the interval between each of the adjacent stars in the sequences, and adopt magnitudes found by combining these estimates with the photometric magnitudes. Having thus provided standards of comparison on the same scale for stars in all parts of the sky, a variable may be compared on any night with the stars nearest it in brightness in its sequence, taking care to select one that is brighter and another fainter. From estimates of these intervals in grades, the light of the variable is readily reduced to the standard scale. When a variable is faint, it is impossible to observe it for several days every month near the time of full Moon. At least one observation should be obtained in the interval between successive times of full Moon. This can be done only for polar stars, owing to the proximity of the Sun at certain seasons. Since the periods of a large portion of the variables of long period exceed half a year, it is evident that monthly observations will, in general, give a good idea of the form of the light curve. Of course, additional observations should also be obtained, but failure to secure any observation during a long interval should be avoided, if possible. Since 1889 an attempt has been made to observe seventeen circumpolar variables north of declination $+50°$ at least once a month. These stars are always above the horizon at Cambridge, so that they can be observed at all seasons. The results for the years 1889–1899 will be found in Volume XXXVII, Part I, of the *Annals*, which is now printed and in process of distribution. Similar observations have been made of about sixty other variables, but less regularly. At Arequipa similar observations have been made of a large number of southern variables. It is much to be desired that all variables of long period should be observed in the same way, or at least so that all can be reduced to a uniform scale of magnitudes. Coöperation is necessary to attain success in this work. Variables near the ecliptic can be observed when near the Sun much better at tropical stations than at those near the pole. The reverse is true for polar variables. Northern variables can be observed for a longer portion of the year at northern observatories, and southern variables at southern observatories. When a variable can be observed only in the morning, it is much more likely to escape observation than at

other seasons. A computation has been made of the date on which the variables mentioned above are 20° above the horizon at Cambridge at midnight, and also in the morning and evening when the Sun is still 10° below the horizon. Thus these three dates for the star *T Andromedæ* are July 1, May 1, and March 12. Accordingly, from May 1 to July 1 this star can be observed only in the morning, from July 1 to March 12 it can be observed in the evening, while from March 12 to May 1 observations are difficult owing to twilight. When a variable is bright it is best observed with a small telescope, that is, one having an aperture of not more than 6 or 8 inches. Observations of great value could be obtained by an observer with a large telescope if he was notified when the star was too faint to be observed with smaller instruments. The excellent charts of Father Hagen are almost indispensable for observing the stars when fainter than the ninth magnitude. When the variables are bright, the need has been felt here for charts on a smaller scale and covering a larger region. After various experiments, photographic enlargements have been made of portions of the admirable charts of the Bonn *Durchmusterung*. A region 3° square surrounding each variable has been enlarged three times, thus giving a map on the standard scale of one minute of arc to one millimeter. The stars on these maps, while appearing coarse by daylight, are thus easily seen and identified at night without using a light bright enough to dazzle the eye. The designations of the stars in the sequence are marked upon these enlargements, and copies will be furnished at cost. Charts will be furnished free of cost to experienced observers who are ready to coöperate in the above plan of work. Observations of nearly equal value can be obtained by those unaccustomed to estimating intervals in grades. It is only necessary to enter on the charts the standard magnitudes of the comparison stars, and from these to estimate directly the magnitude of the variable. Charts are now being prepared, and with the corresponding magnitudes can soon be furnished for the following stars:

T Andromedæ, T Cassiopeiæ, R Andromedæ, S Ceti, S Cassiopeiæ, R Piscium, R Arietis, o Ceti, S Persei, R Ceti, U Ceti, R Tauri, R Aurigæ, U Orionis, R Lyncis, R Geminorum, S Canis Minoris, R Cancri, V Cancri, S Hydræ, T Hydræ, R Leonis Minoris, R Leonis, R Ursæ Majoris, X Virginis, R Comæ Berenices, T Virginis, R Corvi, Y Virginis, T Ursæ Majoris, R Virginis, S Ursæ Majoris, U Virginis, V Virginis, R Hydræ, S Virginis, R Canum Venaticorum, S Boötis, R Camelopardali, R Boötis, S Libræ, S

Serpentis, S Coronæ Borealis, R Herculis, R Scorpii, S Scorpii, U Herculis, V Herculis, R Ursæ Minoris, R Draconis, S Herculis, R Ophiuchi, T Herculis, R Scuti, R Sagittarii, R Cygni, χ Cygni, S Cygni, RS Cygni, R Delphini, U Cygni, V Cygni, T Aquarii, R Vulpeculæ, T Cephei, S Cephei, SS Cygni, S Aquarii, R Pegasi, S Pegasi, R Aquarii, and R Cassiopeiæ.

If the above plan proves successful, it is hoped that it may be extended to the other variable stars of long period.

EDWARD C. PICKERING.

ANDERSON'S NEW STAR IN *PERSEUS*.[1]

THE cable message announcing the discovery of a new star in the constellation *Perseus* by the Rev. T. D. Anderson was received at the Observatory early in the evening of February 22, 1901. Owing to clouds, the new star was only occasionally visible, and twice it was necessary to cover the instruments on account of falling snow. During the intervals, however, various observations were made, which have a value owing to their early date. Numerous comparisons by Miss Cannon with α *Aurigae*, magnitude 0.21, α *Orionis*, magnitude 0.92, and α *Tauri*, magnitude 1.06, showed that the magnitude of the star was about 0.9. Photometric comparisons by Professor Wendell with the 15-inch telescope, of the *Nova* with the star $+43^\circ 732$, magnitude 7.25, at $14^h\ 0^m$ and at $17^h\ 25^m$, Greenwich Mean Time, gave the magnitudes 0.35 and 0.39, respectively.

Meanwhile an examination was being made by Mrs. Fleming of the photographs of the region obtained here earlier in the month, with the various instruments. Although photographs are taken with the transit photometer throughout every clear night, yet owing to twilight they cannot be taken as early in the evening as this star culminates. Fortunately, for some weeks the work of the transit photometer, which photographs objects only near the meridian, has been supplemented by photographs with Cooke and Ross-Zeiss Anastigmat lenses. With these instruments, an attempt is made to cover the entire sky, both east and west of the meridian, at short intervals. The completeness with which this has been done is shown by the fact that we have photographs of the region of the *Nova* with the Cooke lens on February 8, 18, and 19, and with the Ross-Zeiss lens on February 2, 6, 18, and 19. The photograph taken with the Cooke lens on February 19

[1] *Harvard College Observatory Circular* No. 56.

had an exposure of 66^m, beginning at 11^h 18^m Greenwich Mean Time, While this photograph showed not only the faintest stars contained in the *Durchmusterung*, but also stars as faint as the eleventh magnitude, no trace of the *Nova* was seen. This result was confirmed by the other plates mentioned above. A general examination of the large number of earlier plates of this region did not seem to be necessary. Plates taken with the 8-inch Bache telescope as early as November 6, November 8, and December 12, 1887, fail to show the *Nova*, although the spectra of stars as faint as the eighth magnitude are clearly visible on all, and those of the ninth magnitude, on the plate taken on November 6. A photograph taken with the 24-inch Bruce telescope on October 18, 1894, with an exposure of 15^m, shows no trace of this object, although stars as faint as the magnitude 12.5 are well seen.

On this same evening, February 22, eighteen photographs were taken with various instruments under the direction of Mr. Edward S. King. They showed that, photographically, the *Nova* was 0.3 fainter than *α Aurigae*. The general appearance of the photographic spectrum resembled that of the *Orion* type and was very unlike that of other new stars, in which the bright lines are the most conspicuous feature. This star had a strong continuous spectrum traversed by 33 dark lines. The approximate wave-lengths, as derived by Hartmann's formula, from the measures of $H\epsilon$, $H\gamma$, and $H\beta$, are given below. Each is followed by its relative intensity, and by the difference found by subtracting it from the wave-length of the corresponding line, if any, in the spectrum of *β Orionis*. As the lines having greater wave-length than 5000 have thus been determined by extrapolation, they may be subject to large systematic errors.

3894, 10, $H\zeta$, —5; 3970, 20, $H\epsilon$, 0; 4026, 3, 0; 4077, 2,—1; 4102, 30, $H\delta$, 0; 4126, 5, +2; 4151, 1, —4; 4266, 2, +1; 4341, 40, $H\gamma$, 0; 4366, 1, +1; 4388, 2, 0; 4415, 1; 4435, 1, +3; 4470, 2, +2; 4481, 20, 0; 4510, 2, —2; 4530, 2; 4552, 2; 4572, 1; 4616, 1; 4643, 1; 4665, 3; 4714, 3, —1; 4862, 40, $H\beta$, 0; 4885, 2; 4922, 2, 0; 5325, 1; 5399, 1; 5431, 1; 5677, 2; 5695, 7; 5719, 5; and 5761, 1. On careful examination the lines 3970, 4102, 4341, 4481, and 4862 were seen to be bright on the edge of greater wave-length. The line 4665 was bright on the edge of shorter wave-length, or there was a bright line whose approximate wave-length was 4660. The line 4026 was not measured, but identified from its position.

On February 23, the clouds were so dense that few observations

could be made. The star appeared to be brighter and bluer than *α Aurigae*, and to have the approximate magnitude 0.0. The spectrum was photographed faintly and showed no marked change except that the line K, which was absent on the previous evening, was present and nearly as intense as *Hε*.

On February 24, it became clear soon after noon, and at one o'clock the *Nova* was seen with the 6-inch equatorial, and also with the 2-inch finder, in strong sunlight. In the evening, the magnitude according to visual comparisons, was 0.54, from measures with the 15-inch equatorial, 0.59, and with the meridian photometer, in strong daylight, 0.28. Photographically it was 0.4 or 0.5 fainter than *α Aurigae*. The spectrum showed a remarkable change. It was traversed by numerous bright and dark bands, and closely resembled that of *Nova Aurigae*. The principal lines were dark with accompanying bright lines of somewhat greater wave-length. The bright lines accompanying K and *Hε* were reversed, and traversed by narrow well defined dark lines. These last lines, and one of somewhat shorter wave-length than *Hβ*, are the only sharply defined lines in the spectrum, all of the others being broad and hazy, and difficult to measure with accuracy.

Clouds interfered with observations on February 25, but the *Nova* was evidently much fainter than on the previous evening. Its magnitude from visual comparisons was 1.4, from photometric measures, 1.07. The spectrum differed slightly from that on February 24. The lines *Hδ*, *Hγ*, and *Hβ* were also reversed and replaced by one or more narrow dark lines.

On February 26, the magnitude from visual comparisons was 1.3, from photometric measures 1.49. The changes in spectrum were slight.

Observations of the position of the *Nova* were made by Mr. J. A. Dunne, with the 8-inch meridian circle, on February 23, 24, and 25, with the result for 1900.0, R.A. $3^h\ 24^m\ 24^s.02$, Dec. $+43^\circ\ 33'\ 42''.4$.

It therefore appears that on and before February 19, 1901, the star was invisible, or at least fainter than the eleventh magnitude. On February 21, its magnitude was 2.7, according to Mr. Anderson. On February 22, its magnitude was 0.5, perhaps becoming a little brighter on February 23, and then diminishing, so that on February 25 its magnitude was 1.1. Its spectrum on February 22 and 23, was of the *Orion* type, nearly continuous, traversed by narrow dark lines. During the next 24 hours an extraordinary change took place, so that on February 24 the spectrum resembled that of the other *Novae*. It was

traversed by bright and dark bands, and the principal dark lines had accompanying bright lines of slightly greater wave-length.

During the last fourteen years, and since the general application of photography to astronomy, eight new stars are known to have appeared, *Nova Persei*, in 1887; *Nova Aurigae*, in 1891; *Nova Normae*, in 1893; *Nova Carinae*, in 1895; *Nova Centauri*, in 1895; *Nova Sagittarii*, in 1898; *Nova Aquilae*, in 1899; and *Nova Persei*, in 1901. The second and last of these, which were much brighter than the others, were found visually by Dr. Anderson. All of the others were found by Mrs. Fleming, from an examination of the Draper Memorial Photographs. *Nova Aquilae* was announced by telegraph, but has not been described in these circulars. Its position for 1900 is R.A. 19^h $15^m.3$, Dec.—$0°$ $19'$. It was not seen on plates taken on November 1, 1898, and earlier, although stars of the thirteenth magnitude appeared on some of them. On April 21, 1899, it was seventh magnitude. It appears on eighteen photographs taken during that summer, and on October 27, 1899, it was tenth magnitude. In July 1900, when it was discovered, it was about twelfth magnitude. Seven bright lines $H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$, 4693, $H\beta$, and the nebular line 5007, were seen in the spectrum photographed on July 3, 1899. On September 7, 1899, $H\gamma$ and a somewhat fainter line, which is probably 4959, were the only bright lines visible. On October 27, 1899, $H\gamma$ and 5007 were alone visible and bright, so that the spectrum had then become that of a gaseous nebula.

EDWARD C. PICKERING.

February 27, 1901.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

BULLETIN NO. 16.

THE NEW STAR IN *PERSEUS*.

THE first news of Anderson's discovery of a new star in *Perseus* was received at this Observatory on February 24. An examination of the region near the star, made that evening with the 40-inch telescope, failed to show any evidence of nebulosity, but the bright moonlight would have rendered a faint nebula invisible. At that time the magnitude of the star appeared to be about 0.5. Its color was yellow, with a

decided reddish cast, very similar to that of *α Orionis*. Very little time was spent in examining the spectrum visually, as it was felt that photographs would be more valuable than drawings based on micrometer measures. We had fortunately just received a fresh supply of Erythro plates through the kindness of the International Color-Photo Company of Chicago, and it was therefore possible to photograph the entire spectrum from $H\alpha$ to $H\iota$. Beyond this point in the ultra-violet the absorption of the 40-inch objective greatly enfeebles the spectrum, which is still further weakened by the lack of perfect achromatism in this region.

Photographs of the spectrum have been obtained by Mr. Ellerman as follows:

Date	No. of plates	Dispersion	Region
1901, Feb. 24	5	3 prisms	$H\beta$ to $H\gamma$, Bruce spectrograph
24	5	3 prisms	D to 4400
24	1	3 prisms	$H\alpha$ to 4500
25	3	3 prisms	$H\beta$ to $H\gamma$, Bruce spectrograph
25	3	3 prisms	D to 4400
25	3	1 prism	5700 to 3700
25	1	1 prism	$H\alpha$ to 3900
26	3	3 prisms	D to 4400
26	1	1 prism	$H\alpha$ to 3900
27	8	3 prisms	D to 4400
27	1	3 prisms	$H\alpha$ to 4500
27	6	1 prism	5700 to 3700
28	5	1 prism	5700 to 3700
28	2	1 prism	$H\alpha$ to 3900
28	3	3 prisms	D to 4400
Mar. 4	3	1 prism	5700 to 3700
4	1	1 prism	$H\alpha$ to 3900
6	2	3 prisms	D to 4400
6	1	3 prisms	$H\beta$ to $H\gamma$
6	1	1 prism	5700 to 3700
11	3	3 prisms	D to 4400
11	1	1 prism	5700 to 3700

The comparison spectra which appear on these plates are those of titanium, hydrogen, and sodium.

On February 24 and 25 Mr. Ritchey photographed the region of the *Nova* with the 40-inch telescope and color screen. In order to obtain a sufficient number of comparison stars the plates were given an exposure of one hour. The light of the *Nova* was intercepted by a small movable occulting disk, with which four (for the second plate, five) very brief exposures were given at intervals of about fifteen minutes.

PLATE III.

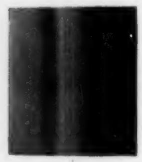


FIG. 1.—D_3 AND THE SODIUM LINES.

FIG. 2.—REGION $H\alpha$ TO D.

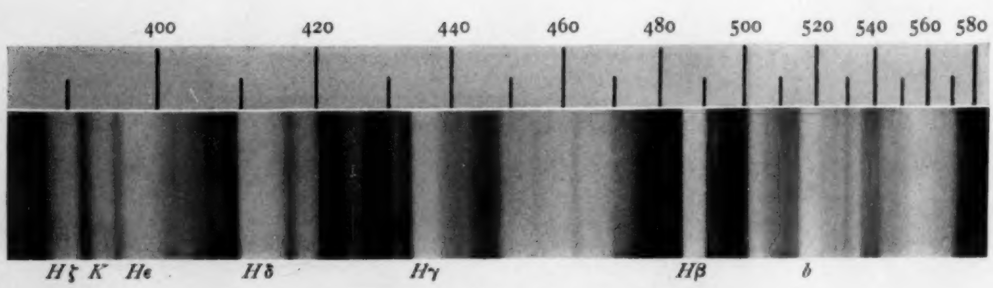


FIG. 3.—SPECTRUM OF *NOVA PERSEI*, FEB. 28, 1901.

The total exposure for the *Nova* was probably about half a second. In the resulting photographs, the images of the *Nova* and the neighboring stars (of which more than forty appear in a region 12′ square) are small and appear to be well adapted for measurement. Through the kindness of Director Rees, these plates will be measured at the Columbia College Observatory. The position of the *Nova* was measured micrometrically by Professor Burnham on March 3.

The wedge photometer used with the 40-inch telescope in the determination of standards of faint stellar magnitude has been employed by Mr. Parkhurst in measuring the brightness of the *Nova*. Hitherto objectives of one and two inches aperture have sufficed, but as the *Nova* decreases in brilliancy it will be followed with the 12-inch and 40-inch telescopes. A preliminary reduction gives the following magnitudes :

Date	Mag.	Date	Mag.
1901, Feb. 25	1.0	1901, Mar. 3	2.7
26	1.1	4	2.8
27	2.0	5	2.7
28	1.9	6	3.1

A photograph of the spectrum (G 440) taken with the one prism spectrograph on February 28 has been measured by the writer. The resulting wave-lengths of the lines and bands, computed by the aid of Cornu-Hartmann formulæ, furnished data for attaching a scale to an enlargement of the photograph reproduced in Fig. 3, Plate III.

Inspection of the photograph will show that the spectrum is very similar to the earlier spectrum of *Nova Aurigae*. The hydrogen lines, notably C (Fig. 2) and F, are bright and very broad. The dark lines superposed upon them (not shown in the cut) are probably reversals caused by the absorption of an outer layer of cooler gas at lower pressure.

On the more refrangible side the hydrogen lines are accompanied by dark lines, just as was the case with *Nova Aurigae*. As Wilsing has shown, this is doubtless due to the great pressure under which the radiation occurs. The bright sodium line has broadened into a band, on which appear the two dark D lines (Fig. 1). These appear on the photographs, and are clearly visible in visual observations with a three-prism spectroscope. As the titanium poles were moistened with a weak solution of sodium chloride, the comparison spectrum contains the bright sodium lines. Thus the motion of the star in the line of

sight can be measured. Some preliminary determinations indicate that the *Nova* is moving away from the Earth at a low velocity.

The helium line D_3 seems to be present as a dark line, lying close to the bright sodium band on the more refrangible side (Fig. 1). The bright calcium lines H and K are notable for their great breadth and for the narrow lines of reversal which traverse them. The chief nebular line seems to be present (λ 5002 — 5041), and a fainter line or band (λ 4911—4988) covers the region of the second nebular line. The *b* group of magnesium is doubtless represented by the very bright band λ 5154 — 5204. The green coronal line (λ 5303) would fall near the more refrangible edge of a bright band in the spectrum of the *Nova*.

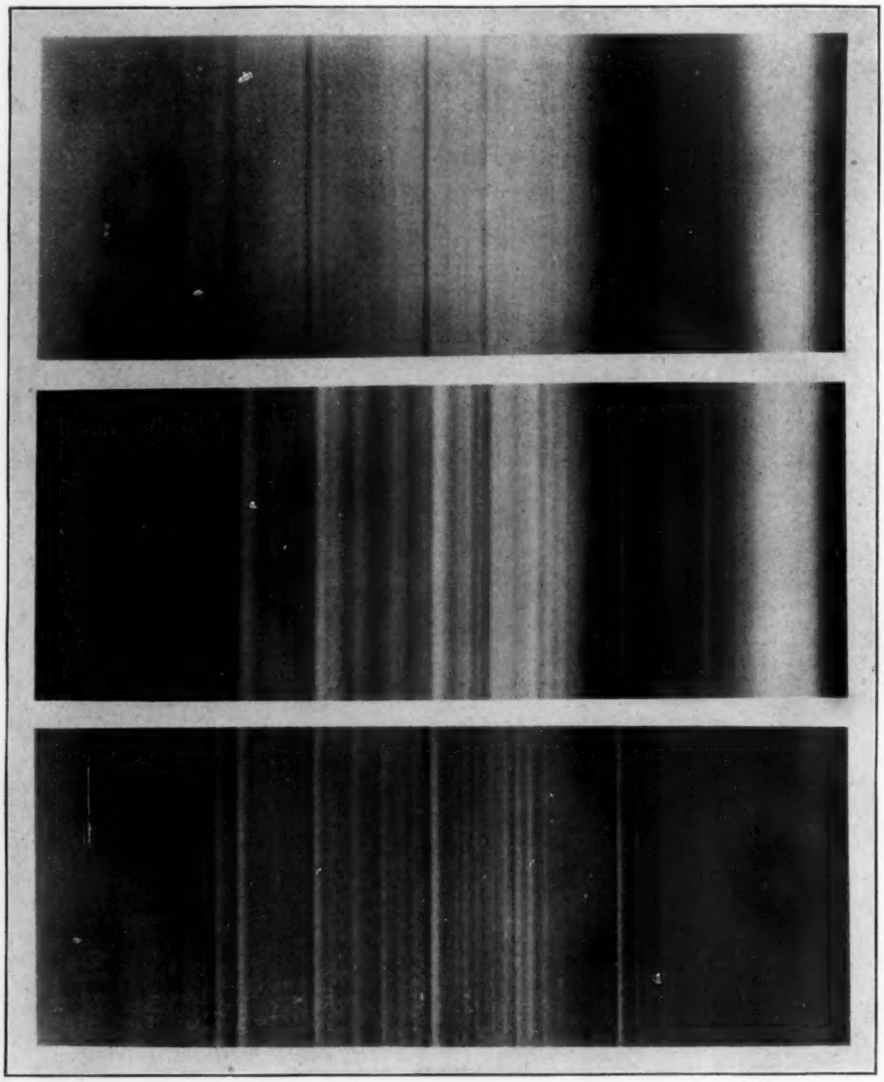
Further results, based upon measurements of photographs taken with the three-prism spectrograph, will be given in a subsequent paper.

Note added March 18.—A comparison of photographs taken on March 4 and March 15 shows that the dark lines on the more refrangible edge of the bright hydrogen lines continue to increase in sharpness. At first single and rather diffuse, they have become sharply defined double lines. K is much fainter than before, and *b* is apparently decreasing in intensity.

George E. Hale.

March 12, 1901.

PLATE IV



SPECTRA OF *NOVA PERSEI* AND *NOVA AURIGAE*

PHOTOGRAPHED AT HARVARD COLLEGE OBSERVATORY

1. *Nova Persei*, February 22, 1901. 2. *Nova Persei*, February 24, 1901. Isochromatic Plates.
3. *Nova Aurigae*, February 5, 1892. Ordinary Plate.